NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 375

FULL-SCALE TESTS OF METAL PROPELLERS AT HIGH TIP SPEEDS

By DONALD H. WOOD

1931

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/s		horsepower	hp
Speed		km/h	k. p. h.	mi./hr.	m. p. h.
		m/s	m. p. s.	ft./sec.	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s$^2=32.1740$ ft./sec.^{2}

m, Mass $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C. and 750 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}.

mk^2, Moment of inertia (indicate axis of the radius of gyration k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord.

$\frac{b^2}{S}$, Aspect ratio.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$.

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{D_o}=\frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i}=\frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p}=\frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force.

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting (relative to thrust line).

Q, Resultant moment.

Ω, Resultant angular velocity.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, at 15° C., the corresponding number is 234,000;

or for a model of 10 cm chord 40 m/s, the corresponding number is 274,000.

C_p, Center of pressure coefficient (ratio of distance of $c. p.$ from leading edge to chord length).

α, Angle of attack.

ϵ, Angle of downwash.

α_o, Angle of attack, infinite aspect ratio.

α_i, Angle of attack, induced.

α_a, Angle of attack, absolute.
(Measured from zero lift position.)

γ, Flight path angle.

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36338—31——1

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

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REPORT No. 375

FULL-SCALE TESTS OF METAL PROPELLERS AT HIGH TIP SPEEDS

By Donald H. Wood

SUMMARY

This report describes tests of 10 full-scale metal propellers of several thickness ratios at various tip speeds up to 1,350 feet per second. The tests were made in the Propeller Research Tunnel of the National Advisory Committee for Aeronautics at Langley Field, Virginia.

The results indicate no loss of efficiency up to tip speeds of approximately 1,000 feet per second. Above this tip speed the loss is at a rate of about 10 per cent per 100 feet per second increase relative to the efficiency at the lower speeds for propellers of pitch diameter ratios 0.3 to 0.4. Propellers having sections of small thickness ratio can be run at slightly higher speeds than thick ones before beginning to lose efficiency.

INTRODUCTION

As a result of extensive research, the design of aircraft propellers can be carried out now with satisfactory accuracy in most instances. There yet remain some phases of the problem, such as the design of propellers to operate at high tip speeds, for which available data are contradictory.

The forces acting on a body moving uniformly in a fluid depend mainly on the size, shape, and orientation of the body; its speed; the properties of the fluid; and in some cases the value of the earth's attraction. By means of the "Theory of Dimensions" given in standard textbooks (Reference 7), it is shown that the force on a body varies as

$$\rho V^2 L^2 f\left[\left(\frac{VL}{\nu}\right), \left(\frac{Lg}{V^2}\right), \left(\frac{V}{c}\right), \text{------etc.}\right]$$

where

ρ = density of the fluid,
V = velocity of the body relative to the fluid,
L = any characteristic length of the body,
ν = coefficient of kinematic viscosity,
c = velocity of sound in the fluid,
g = acceleration due to gravity,
f = function.

The first part only of the above expression ($\rho V^2 L^2$) is given definitely by dimensional theory and was formerly used in expressing the law of variation of the resistance of bodies. The force is also a function of a number of nondimensional expressions, three of which are given in the brackets. The first of these $\frac{VL}{\nu}$, commonly known as Reynolds number, is now known to be of great importance, particularly in passing from model to full scale. The second $\left(\frac{Lg}{V^2}\right)$ is mainly of importance where the body is moving near the free surface of the fluid. It would apply in the case of boats, since waves might be produced. In aerodynamics this function may be neglected, since the bodies move in the interior of the fluid. The functions $\rho\ V^2\ L^2$ and $\left(\frac{VL}{\nu}\right)$ contain the important variables ρ, μ, L, V, in most problems in aeronautics. In propellers, however, where the blade tips may operate at speeds near or above the velocity of sound, the third term within the bracket $\left(\frac{V}{c}\right)$ becomes of importance. As the velocity of the propeller tip approaches the speed of sound, the density of the fluid in the vicinity of the body is appreciably changed. We therefore speak of the effect of this function as the "compressibility effect." Clearly the separation of the functions is merely for convenience of discussion; in fact, all the variables operate simultaneously in a given case.

When the propeller tip speeds approach the velocity of sound as they do with modern direct-drive, high-powered engines, the theory of propeller action is still incomplete, and test results are so dependent on scale that the designer is on less firm ground. Many model tests made for the British Aeronautical Research Committee are reported in Reference 1. A few tests reported in Reference 6 were made with a full-scale propeller up to tip speeds of 900 feet per second. It is apparent from an examination of all these test results that the model propellers have, throughout the range of the tests, larger losses in efficiency at high tip speeds than the full-scale propellers. The results of a number of tests of airfoils at high speeds reported in References 2, 3, 4, and 5 indicate that the loss of effectiveness of propellers at high speeds is due to the change in airfoil characteristics. The fact that the results of some of the recent model tests made at higher values of Reynolds Number than the first tests, and the full-scale tests, also at high values of Reynolds Number, indicate less loss of efficiency, leads to the conclusion that the Reynolds Number is interrelated with the "compressibility effect" in such a way that the "compressibility effect" is less at higher Reynolds Numbers than at low.

Because of this interrelation and also in view of the well-known discrepancies between model and full-scale propeller tests, particularly the effect of the different deflections, it seemed advisable to secure some directly applicable results from tests of full-size propellers. Many full-scale tests have been made in the Propeller Research Tunnel of the National Advisory Committee for Aeronautics, and the results have been reported as they became available. The present tests relating directly to the tip-speed problem are a continuation of this work. Ten propellers were tested at tip speeds from 500 to 1,350 feet per second. Of the 10, 4 were of standard plan form and thickness and the other 6 were of standard form, but were of different thicknesses and sections, three thicknesses in each of two sections. The results of over 160 tests made on these propellers are here reported.

APPARATUS AND METHODS

The Propeller Research Tunnel with its test equipment and methods has been described in Reference 8. The regular test-fuselage and torque dynamometer were used in these tests. The standard metal fuselage framework containing the torque dynamometer was surrounded by a fabric-covered wood fuselage simulating that of an airplane. A Curtiss D-12, 435-horsepower engine was mounted on the forward plate. The whole was supported on the regular balance with water and gas connections carried up from the floor. Cooling was accomplished by circulating water from a large tank on the floor below, instead of using a radiator. The fuselage as arranged for testing is shown in Figure 1.

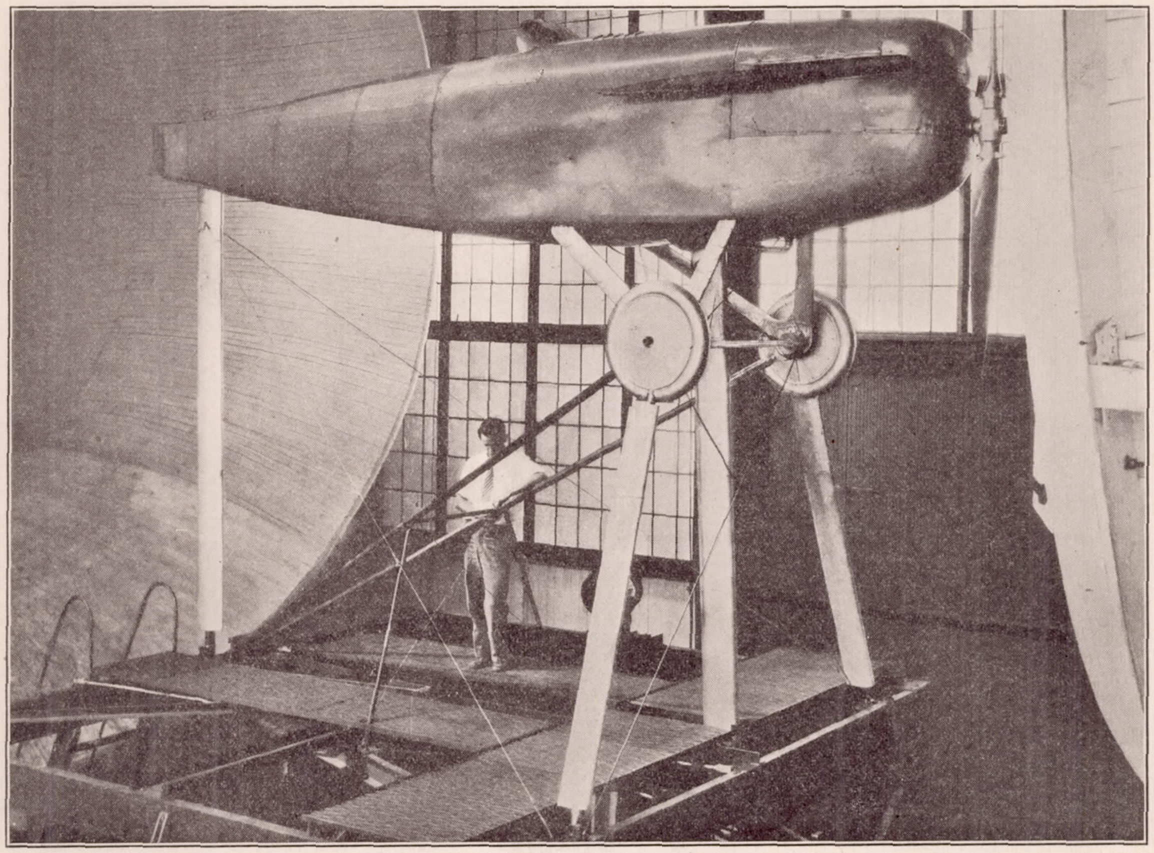


FIGURE 1.—Fuselage mounted for test

The 10 propellers used in this investigation included two series of three propellers each. They were 9 feet 6 inches in diameter and were designed to have a constant thickness ratio over a major portion of the blade. These ratios were 0.06, 0.08, and 0.10. In one series the section was the standard modified R.A.F.-6 propeller section, and in the other the Clark Y section formed by making all ordinates in the same ratio to the maximum ordinate as they are in the Clark Y airfoil. In addition four standard propellers were tested. Two had narrow tips and two, wide tips. One of each was 9 feet in diameter and the other one, geometrically similar, was 9 feet 6 inches in diameter.

For convenience, these propellers are designated R-6, R-8, R-10; C-6, C-8, C-10; S-W-9.5, S-N-9.5, S-W-9, and S-N-9, the letter C meaning Clark Y and R meaning R.A.F.-6 modified. The numbers 6, 8, and 10 represent the thickness ratios 0.06, 0.08, and 0.10. S, W, and N signify standard, wide, and narrow, respectively. The numbers 9.5 and 9 are the diameters.

The reference table correlates these designations with the drawing numbers, which may be familiar to some readers. The diameter, section, and thickness ratio are also given.

REFERENCE TABLE

Report designation	Drawing No.	Diameter	Blade section	Thickness ratio
				Figure 4.
C–6	4877	9 ft.–6 in.	Clark Y	0.06.
C–8	4878	9 ft.–6 in.	Clark Y	0.08.
C–10	4879	9 ft.–6 in.	Clark Y	0.10.
R–6	2125	9 ft.–6 in.	R. A. F. 6 Mod	0.06.
R–8	2124	9 ft.–6 in.	R. A. F. 6 Mod	0.08.
R–10	2123	9 ft.–6 in.	R. A. F. 6 Mod	0.10.
				Figure 5.
S–W–9.5	4413	9 ft.–6 in.	R .A. F. 6 Mod	Varying.
S–N–9.5	3791	9 ft.–6 in.	R. A. F. 6 Mod	Varying.
S–W–9	4412	9 ft.–0 in.	R. A. F. 6 Mod	Varying.
S–N–9	3790	9 ft.–0 in.	R. A. F. 6 Mod	Varying.

Figure 2 is a drawing of propeller C–6 and is typical of the six special propellers, since they are all of the same plan form. Figure 3 shows the standard wide-tip propeller (S–W–9.5) and Figure 4 the standard narrow-tip propeller (S–N–9.5). The blade width, thickness, and pitch diameter ratios are given in the nondimensional curves of Figures 5 and 6. From these curves and the section ordinates given in Figure 7, any of the propeller blades can be laid out.

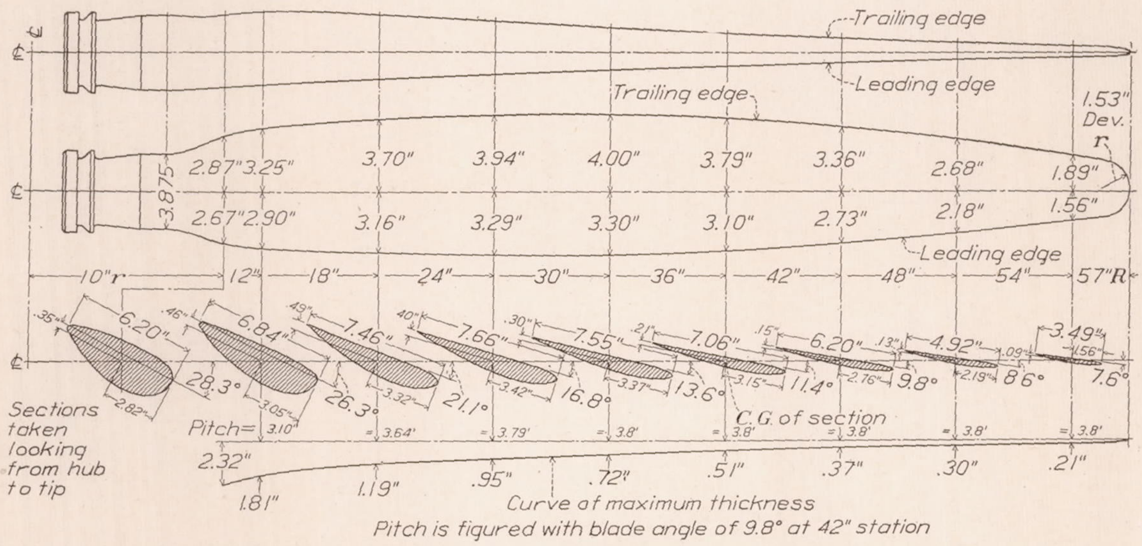


FIGURE 2.—Propeller C–6

ORDINATES OF SECTIONS AT VARIOUS RADII FOR METAL PROPELLER BLADE

9.5 feet diameter, right-hand (fig. 2)

S	10″ r		12″ r		18″ r		24″ r		30″ r		36″ r		42″ r		48″ r		54″ r	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
	Inches	*Inch*	*Inches*	*Inch*	*Inches*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*
0	0.00	0.00	0.17	0.17	0.36	0.36	0.29	0.29	0.22	0.22	0.15	0.15	0.11	0.11	0.09	0.09	0.06	0.06
2.5	.62	.28	.60	.14	.51	.15	.41	.12	.31	.09	.22	.06	.16	.05	.13	.04	.09	.03
5	.84	.44	.86	.21	.70	.10	.56	.08	.43	.06	.30	.04	.22	.03	.18	.02	.12	.02
10	1.13	.59	1.15	.28	.94	.04	.75	.03	.56	.03	.40	.02	.29	.01	.24	.01	.16	.01
20	1.45	.70	1.39	.33	1.16	.00	.92	.00	.70	.00	.50	.00	.36	.00	.29	.00	.20	.00
30	1.58	.74	1.46	.35	1.19	.00	.95	.00	.72	.00	.51	.00	.37	.00	.30	.00	.21	.00
40	1.56	.73	1.45	.35	1.16	.00	.93	.00	.71	.00	.50	.00	.36	.00	.29	.00	.20	.00
50	1.50	.70	1.39	.33	1.07	.00	.86	.00	.65	.00	.46	.00	.33	.00	.27	.00	.19	.00
60	1.38	.64	1.27	.30	.93	.00	.74	.00	.56	.00	.40	.00	.29	.00	.23	.00	.16	.00
70	1.17	.55	1.08	.26	.75	.00	.60	.00	.45	.00	.32	.00	.23	.00	.19	.00	.13	.00
80	.89	.42	.82	.20	.53	.00	.42	.00	.32	.00	.23	.00	.16	.00	.13	.00	.09	.00
90	.55	.26	.51	.12	.28	.00	.23	.00	.17	.00	.12	.00	.09	.00	.07	.00	.05	.00
Rad. L. E	.72		.17		.15		.12		.09		.07		.05		.04		.03	
Rad. T. E	.21		.16		.01		.01		.01		.01		.01		.01		.01	
Chord	6.20		6.84		7.46		7.66		7.55		7.06		6.20		4.92		3.49	

The chord is divided into 10 equal parts, or stations, with the one at the leading edge subdivided into halves and quarters. S equals stations in per cent of chord from leading edge.

We note that the designed pitch of the six special propellers is practically constant with radius, except for a slight washout toward the hub. When the blade setting is changed, the pitch diameter ratio is no longer constant with radius and the pitch distribution is as shown. The standard propellers have nearly a constant pitch when set for a $\frac{p}{D}$ of 0.5 at $0.75R$. At the settings used there is a washout of pitch toward the tip as well as toward the hub. This variation of pitch is a standard design practice and has some advantage in reducing propeller-body interference.

The six propellers of the series were tested at their designed pitch (9.6° at $0.75R$) and the thinnest one in each series was also tested at 6.8° at $0.75R$. The 9-foot diameter standard propellers were tested at 10° at $0.75R$ and the 9-foot 6-inch diameter propellers at 6.8° at $0.75R$. These low pitches were necessary to secure high tip speeds with the engine power and tunnel air speed available.

In these tests, the engine revolutions per minute were held constant throughout the entire range of air speeds. Separate tests were made at invervals of 200 r. p. m. from 1,000 to 2,000, and at intervals of 100 r. p. m. from 2,000 to the highest speed that could be obtained, 2,700 r. p. m. in one or two cases.

Simultaneous readings were taken of the thrust, torque, air speed, revolutions per minute, and deflection at the 42-inch radius. Six yawheads placed behind the propeller were connected to a photographically-recording multiple manometer, which took records at the same time. The data obtained from this instrument are being used to compute the airfoil characteristics of the propeller sections. This information will be issued in a later report. Separate tests were made to determine the drag of the fuselage and supports with the propeller removed.

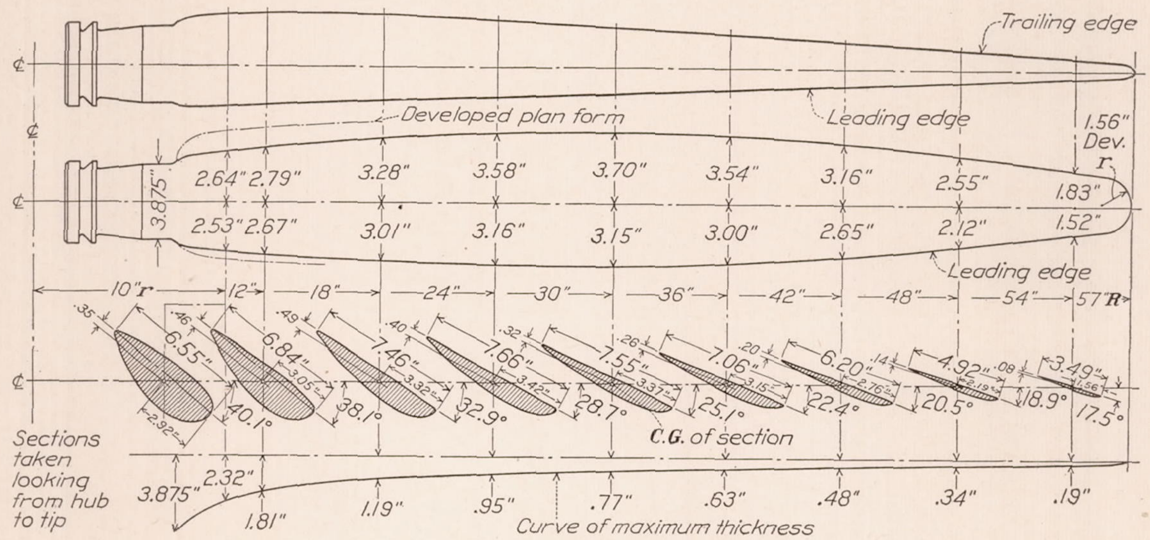


FIGURE 3.—Propeller S-W-9.5

ORDINATES OF SECTIONS AT VARIOUS RADII FOR METAL PROPELLER BLADE

9.5 ft. diameter, right-hand (fig. 3)

S	10″ r Upper	10″ r Lower	12″ r Upper	12″ r Lower	18″ r Upper	24″ r Upper	30″ r Upper	36″ r Upper	42″ r Upper	48″ r Upper	54″ r Upper
	Inches	*Inch*	*Inches*	*Inch*	*Inches*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*
2.5	0.62	0.28	0.68	0.14	0.49	0.39	0.32	0.26	0.20	0.14	0.02
5	.84	.44	.86	.21	.70	.56	.46	.37	.28	.20	.08
10	1.13	.59	1.15	.28	.94	.75	.71	.50	.38	.27	.11
20	1.45	.70	1.39	.33	1.13	.90	.73	.60	.46	.32	.15
30	1.58	.74	1.46	.35	1.19	.95	.77	.63	.48	.34	.18
40	1.56	.73	1.45	.35	1.18	.94	.76	.62	.48	.34	.19
50	1.50	.70	1.39	.33	1.13	.90	.73	.60	.46	.32	.19
60	1.38	.64	1.27	.30	1.04	.83	.67	.56	.42	.30	.18
70	1.17	.55	1.08	.26	.88	.70	.57	.47	.36	.23	.17
80	.89	.42	.82	.20	.67	.53	.43	.35	.27	.19	.14
90	.55	.26	.51	.12	.42	.33	.27	.22	.17	.12	.11
	Inches		*Inches*								
Rad. L. E	.72		.31		.12	.10	.08	.06	.05	.03	.01
Rad. T. E	.21		.16		.09	.07	.06	.05	.04	.03	.07
Chord	6.55		6.84		7.46	7.66	7.55	7.06	6.20	4.92	3.49

The chord is divided into 10 equal parts, or stations, with the one at the leading edge subdivided into halves and quarters. S equals stations in per cent of chord from the leading edge.

The horizontal force which is read on the balance may be either a thrust or a drag. This force R may be considered as made up of the three horizontal components:

T = the thrust of the propeller while operating in front of the body (the tension in the crank shaft).

D = the drag of the body alone (without propeller) at the same dynamic pressure.

ΔD = the change in drag of the body due to the action of the propeller slip stream.

so that

$$R = T - D - \Delta D. \tag{1}$$

To obtain the propulsive efficiency, which includes the propeller-body interference, an effective thrust is used which is defined as

$$\text{Effective thrust} = T - \Delta D,$$
$$\text{or from (1)} \quad = R + D.$$

The power was computed directly from the measured torque and revolutions per minute. An accurately calibrated tachometer was used and the engine was entirely enclosed by cowling, so that no corrections for the slip stream torque reaction on the engine were necessary.

RESULTS

The results are given in Figures 8 to 33, inclusive, and in Table I. The measured values are reduced to the usual coefficients of thrust, power, and propulsive efficiency.

$$C_T = \frac{\text{effective thrust}}{\rho\, n^2 D^4}$$

$$C_P = \frac{\text{input power}}{\rho\, n^3 D^5}$$

$$\eta = \frac{\text{effective thrust} \times \text{velocity of advance}}{\text{input power}}$$

where

D = propeller diameter

and

n = revolutions per unit time

These coefficients are nondimensional and any homogeneous system of units may be used.

The above coefficients were first plotted against the coefficient $\frac{V}{nD}$ and a fair curve drawn through the points. A typical set of such plots is given in Figures 8 to 16, inclusive. These are fairly representative of all the tests and indicate the scattering of the test points, which is one measure of the accuracy of the testing. The torsional deflections computed from the tunnel measurements are also plotted on these figures. All the deflections were uniformly small, averaging about $+\frac{1}{4}°$, although there were some higher values at low values of $\frac{V}{nD}$. These small deflections are in contrast to those found in earlier propeller tests, which gave much higher deflections. Most of this is accounted for by the low pitch of these propellers.

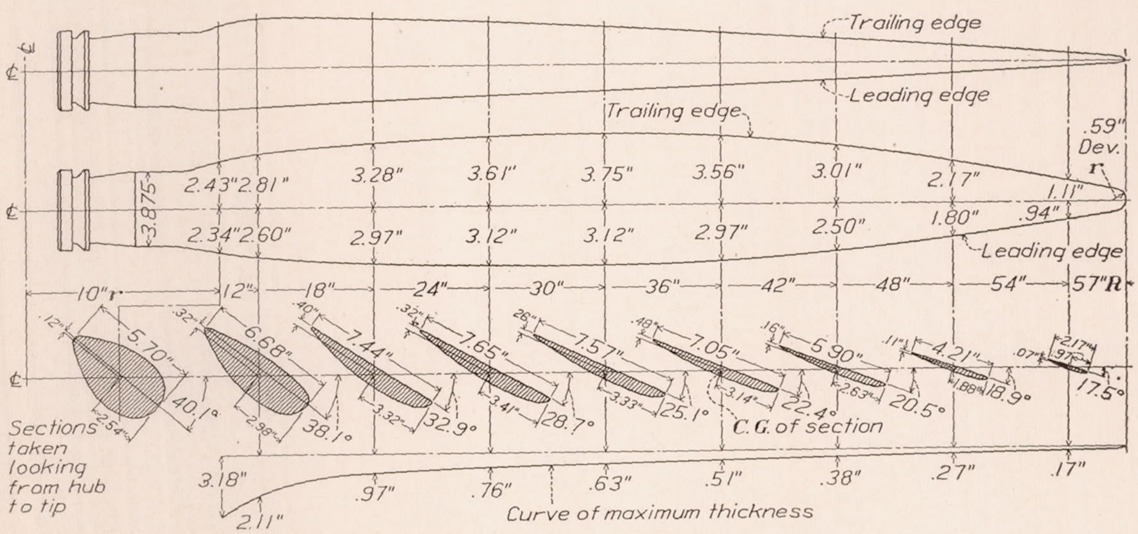


FIGURE 4.—Propeller S–N–9.5

ORDINATES OF SECTIONS AT VARIOUS RADII FOR METAL PROPELLER BLADES

9.5 feet diameter, right-hand (fig. 4)

S	10″ r Upper	10″ r Lower	12″ r Upper	12″ r Lower	18″ r Upper	24″ r Upper	30″ r Upper	36″ r Upper	42″ r Upper	48″ r Upper	54″ r Upper
	Inches	*Inches*	*Inches*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Iuch*	*Inch*
2.5	0.74	0.52	0.59	0.28	0.40	0.31	0.26	0.21	0.16	0.11	0.07
5	.98	.75	.85	.40	.57	.45	.37	.30	.22	.16	.10
10	1.28	1.07	1.14	.53	.77	.60	.50	.40	.30	.21	.13
20	1.59	1.37	1.37	.64	.92	.72	.60	.48	.36	.26	.16
30	1.73	1.45	1.44	.67	.97	.76	.63	.51	.38	.27	.17
40	1.73	1.44	1.43	.66	.96	.75	.62	.50	.38	.27	.17
50	1.66	1.38	1.37	.64	.92	.72	.60	.48	.36	.26	.16
60	1.52	1.26	1.25	.58	.84	.66	.55	.44	.33	.23	.15
70	1.30	1.07	1.07	.50	.72	.56	.47	.38	.28	.20	.13
80	.98	.81	.81	.38	.54	.43	.35	.29	.21	.15	.10
90	.61	.51	.50	.23	.34	.27	.22	.18	.13	.09	.06
Rad. L. E	1.52		.48		.10	.08	.06	.05	.04	.03	.02
Rad. T. E	.34		.17		.07	.06	.05	.04	.03	.02	.01
Chord	5.70		6.68		7.44	7.65	7.57	7.05	5.90	4.21	2.17

The chord is divided into 10 equal parts, or stations, with the one at the leading edge subdivided into halves and quarters. S equals stations in per cent of chord from leading edge.

The faired curves of C_T, C_P, and η were retraced with the curves for all revolution speeds for any one propeller on the same sheet. The C_T and C_P curves from the above-mentioned typical set are given in Figures 17 and 18. All the efficiency curves are given in Figures 19 to 30, inclusive. The close spacing of these curves may lead to confusion, but comparisons between them are made on supplementary curves to be discussed later.

Values of the coefficients read from these faired curves are given in Table I. From these data the curves may be replotted if one desires. The observed data, though kept on file, have not been given, since they would add bulk to the report and would serve no very useful purpose.

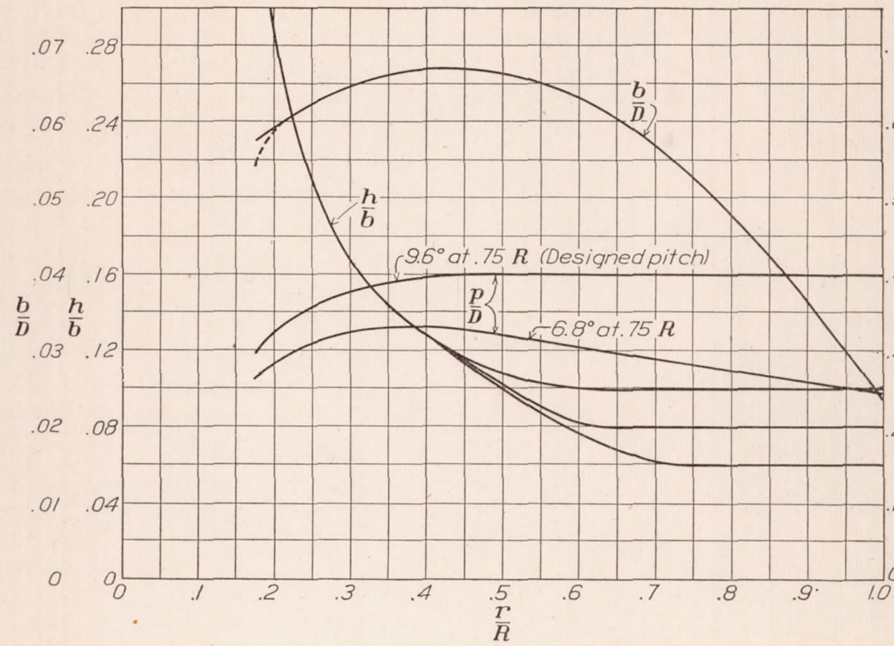


FIGURE 5.—Blade form curves (C and R propellers)

D=diameter
p=pitch
b=blade width
h=blade thickness
r=radius
R=tip radius=$\frac{D}{2}$

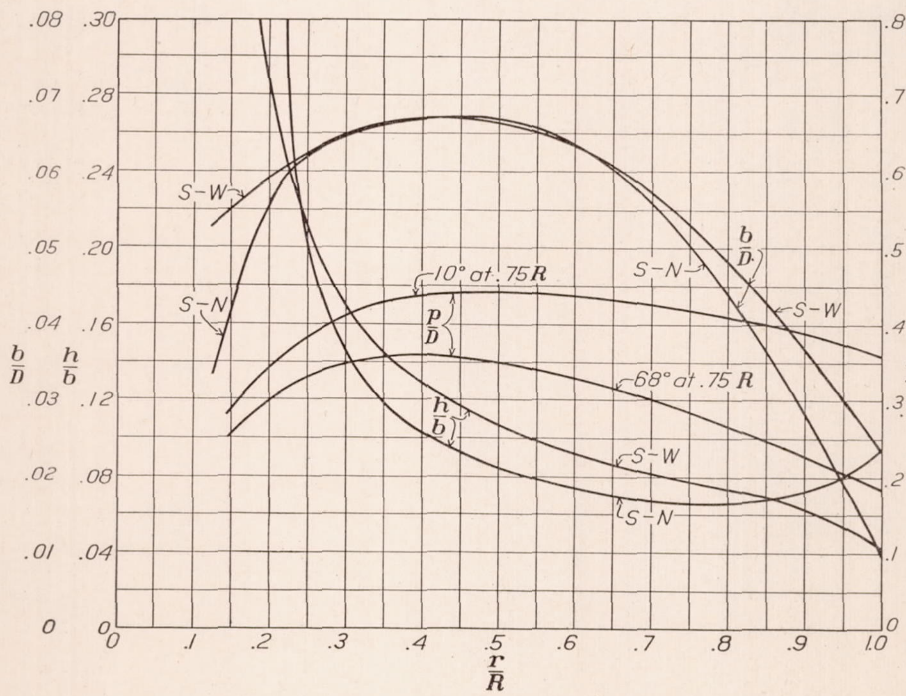


FIGURE 6.—Blade form curves (S propellers)

D=diameter
p=pitch
b=blade width
h=blade thickness
r=radius
R=tip radius=$\frac{D}{2}$

A comparison of the data at different tip speeds can be made from the cross plots of Figures 31, 32, and 33.

These plots give the maximum efficiency and relative maximum efficiency plotted against "tip speed" πnD. Similiar cross plots at other values of $\frac{V}{nD}$ lead to the same conclusions and, therefore, need not be given here.

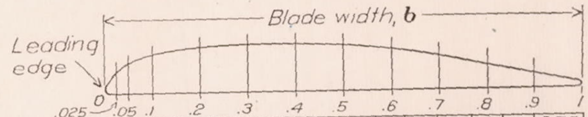
DISCUSSION

Strictly speaking, tip speed should be defined as the speed of the tip of the propeller along the helical path traversed by it with reference to the air. This is equal to the square root of the sum of the squares of the forward speed and of the speed of the tip in the plane of rotation. At the low pitches necessarily employed, this value differs very little (2 per cent maximum) from the tip speed (πDn) due to the rotation alone. For a $\frac{V}{nD}$ of 1.4 the difference is 10 per cent, which is quite appreciable. We shall consider the term "tip speed" as meaning the tip speed of the propeller (πDn) due to rotation alone. Attention is called to the fact that in special racing propellers with high forward and rotational speeds at high pitch angles, the actual tip speed would have a somewhat greater value, and due allowance should be made for this fact in applying the results.

An examination of the curves for all the propellers reveals similar characteristics for each. The thrust coefficients, Figure 17, increase with increase of tip speed up to a certain point and then decrease. There is also a crossing over of the curves so that the dynamic pitch is lowered as the tip speed increases. This crossing over appears almost as a fixed point up to the speed where the thrust coefficient drops, and then the curves seem to shift to the left. The point of cross-over is very close to the $\frac{V}{nD}$ of maximum efficiency. The power coefficients C_P increase continuously with tip speed, at first slowly and then more rapidly. The change is also greater in magnitude at the lower values of $\frac{V}{nD}$. (Fig. 18.) Computations indicate that the small changes in the values of the thrust and power coefficients that occur as the tip speed is increased up to the "critical tip speed" are due to the deflections of the blades.

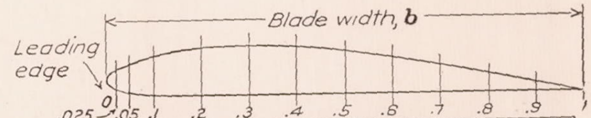
One would expect that, with the thrust and power coefficients increasing, the efficiency would not be seriously affected. In fact, the changes in thrust and power coefficients are at so slow a rate that the efficiency is practically unaffected up to a certain speed. (Figs. 19 to 30, inclusive.) This point is more clearly demonstrated in the cross plots of the maximum efficiency against the tip speed of Figures 31 to 33, inclusive. Clearly the efficiency is constant up to a tip speed varying from 950 to 1050 feet per second. The higher speed corresponds to the thinnest propellers and the lower speed to the thickest propeller; thin and thick referring to thickness chord ratio and not actual thickness.

The actual "peak" efficiency varied with the thickness ratio. In the case of the C series the thickest propeller (C–10) had about 3 per cent higher efficiency than the thinnest (C–6) (72 per cent against 69 per cent). With the R series the thinnest propeller (R–6) had about 3 per cent more efficiency than the thickest (R–10) (66 per cent against 63 per cent). This difference in efficiency can be explained by the fact that the R section is a poorer airfoil than the Clark Y; that is, the L/D ratio is lower for the R section than for the Clark Y, especially at the low angles of attack at which the sections are operating near "peak" efficiency. Since the L/D ratio of sections is a more important factor at low pitch settings than at high pitch settings, a lower efficiency would be expected from the



STATION	R.L.E.	.025	.05	.1	.2	.3	.4	.5	.6	.7	.8	.9	R.T.E.
ORD./MAX. ORD.	.10	.41	.59	.79	.95	1.00	.99	.95	.87	.74	.56	.35	.077

Standard propeller section based on R.A.F -6



STATION	R.L.E.	.025	.05	.1	.2	.3	.4	.5	.6	.7	.8	.9	1
UP. ORD./MAX. ORD.	.13	.56	.68	.82	.97	1.00	.98	.90	.78	.63	.45	.24	.01
LO. ORD./MAX. ORD.		.13	.08	.04	0	0	0	0	0	0	0	0	0

Propeller section based on Clark -Y

FIGURE 7.—Propeller section ordinates (C and R sections)

R propellers. The angle of zero lift has a lower value for a thick airfoil than for a thin one. The dynamic pitch of a propeller will therefore increase with an increase of the thickness ratio with a resulting increase in the "peak" efficiency because of the higher pitch. The L/D ratio of the R section decreases so rapidly with increase of thickness ratio that the advantage of the higher pitch is overcome; and the thickest R propeller is the least efficient. On the other hand, the decrease of the L/D ratio with increase in thickness is less rapid for the C section. Hence, the thickest C propeller is the most efficient.

We note that the "peak" efficiency occurs at about the same value of $\frac{V}{nD}$ with the three R propellers. On the other hand, the thinnest C propeller "peaks" at a higher value of $\frac{V}{nD}$ and the two thicker C propellers at successively higher values of $\frac{V}{nD}$. The angle of attack for maximum L/D ratio is lower for the C section than for the R section. Therefore, "peak" efficiency occurs at a higher value of $\frac{V}{nD}$ for propellers with C sections.

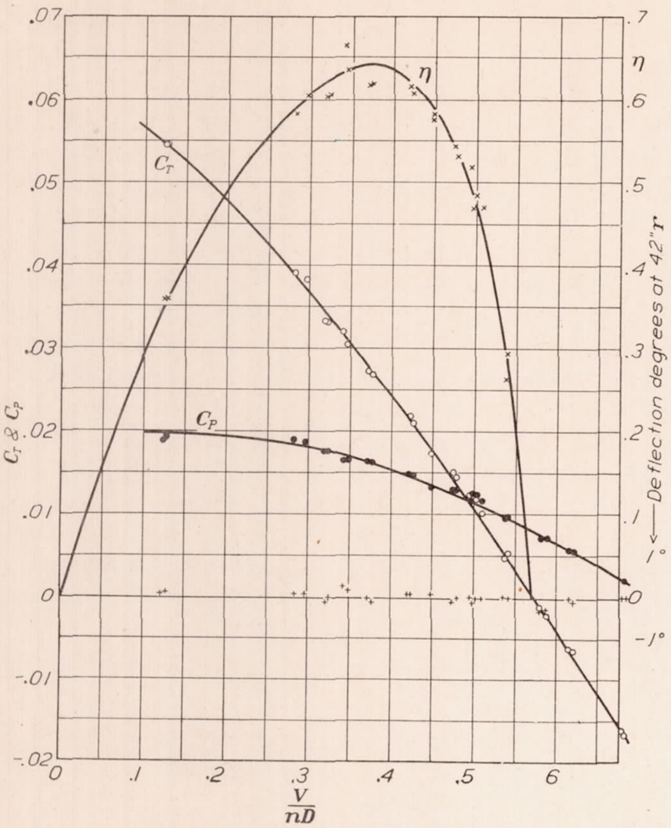


FIGURE 8.—Propeller R-8 set 9.6° at 0.75*R*. 1,000 r. p. m.

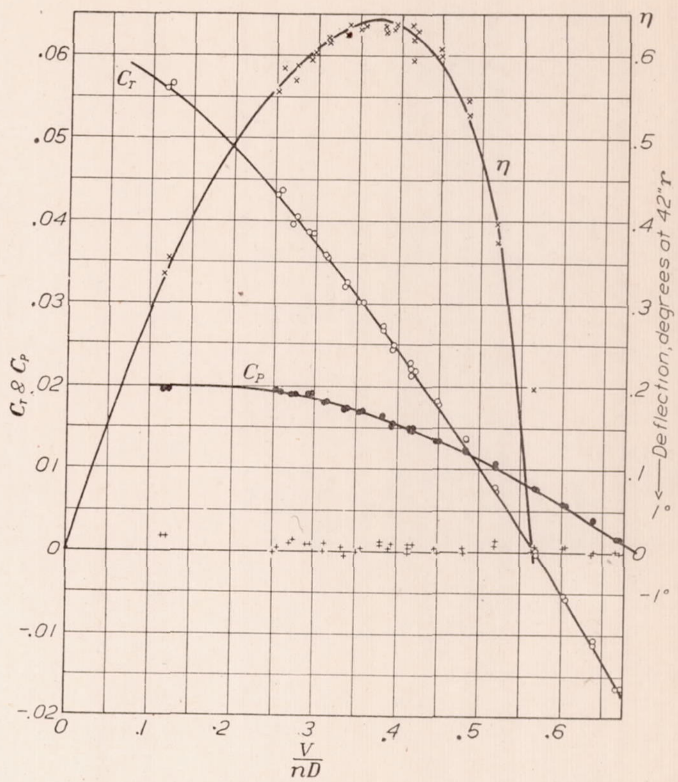


FIGURE 9.—Propeller R-8 set 9.6° at 0.75*R*. 1,200 r. p. m.

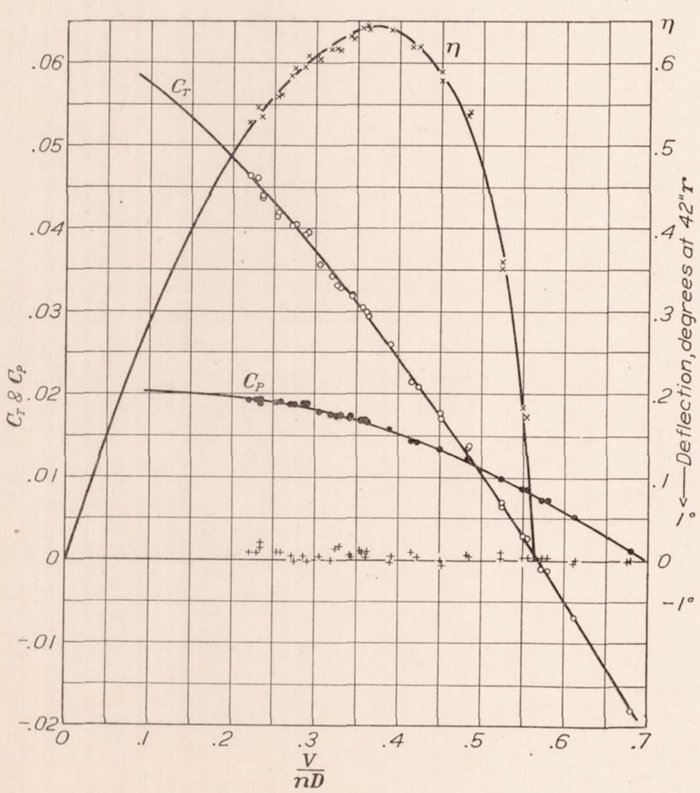


FIGURE 10.—Propeller R-8 set 9.6° at 0.75*R*. 1,400 r. p. m.

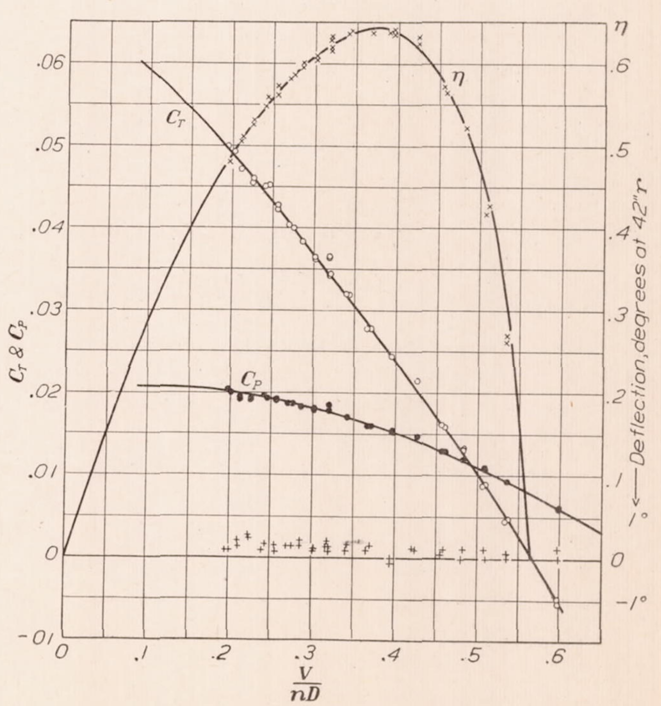


FIGURE 11.—Propeller R-8 set 9.6° at 0.75*R*. 1,600 r. p. m.

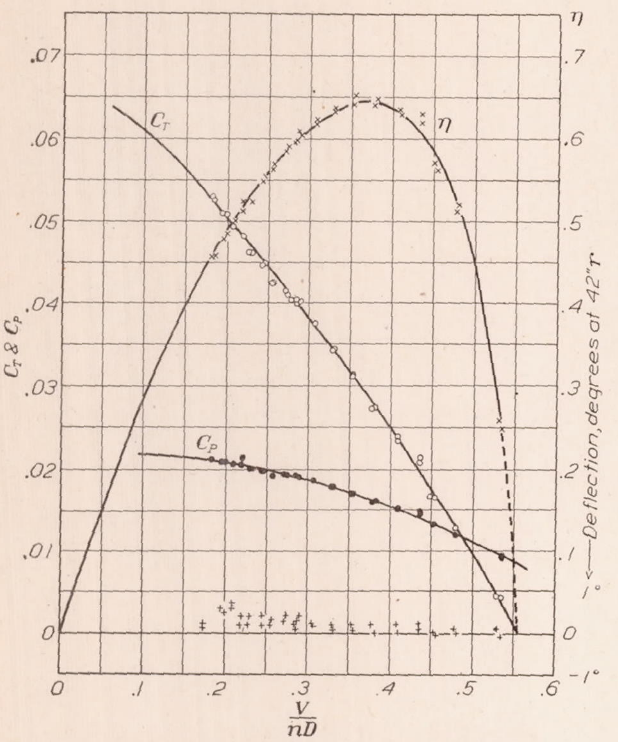


FIGURE 12.—Propeller R-8 set 9.6° at 0.75*R*. 1,800 r. p. m.

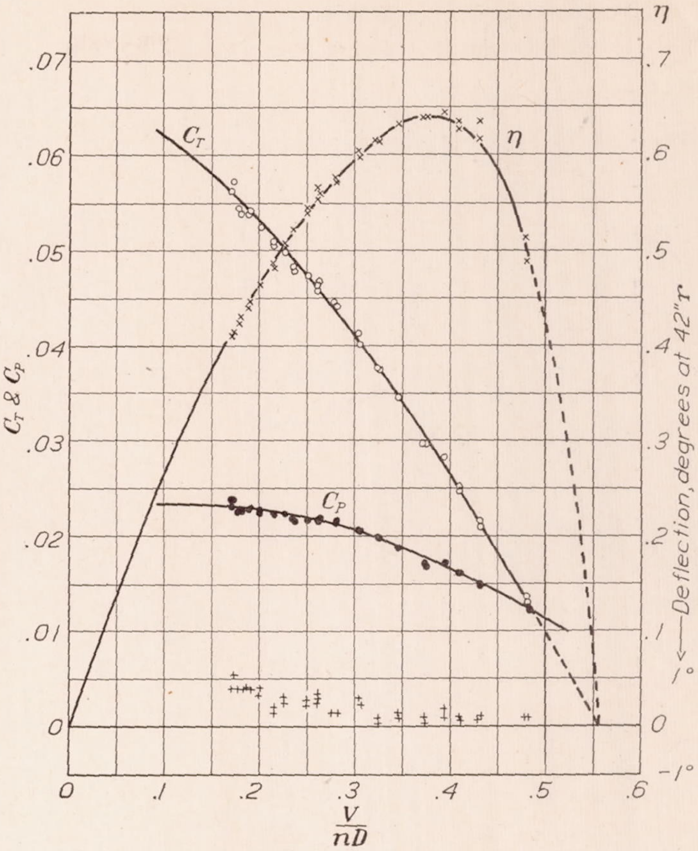


FIGURE 13.—Propeller R-8 set 9.6° at 0.75*R*. 2,000 r. p. m.

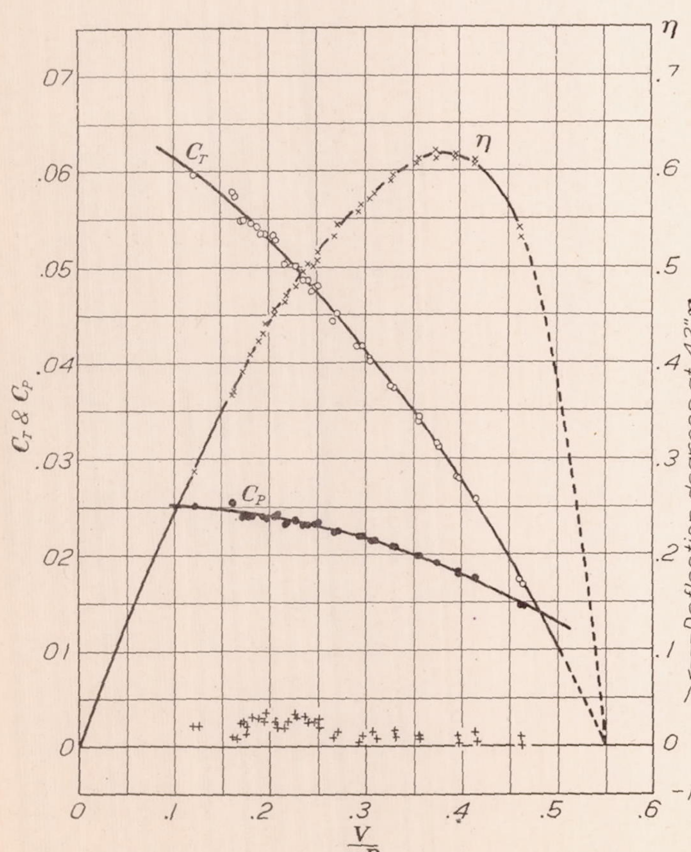


FIGURE 14.—Propeller R-8 set 9.6° at 0.75*R*. 2,100 r. p. m.

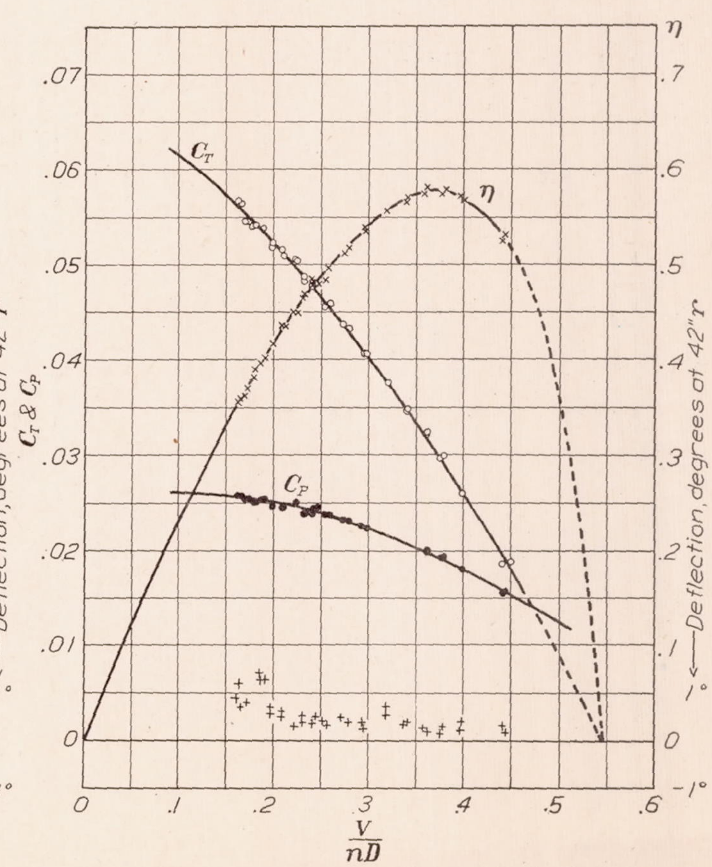


FIGURE 15.—Propeller R-8 set 9.6° at 0.75*R*. 2,200 r. p. m.

The fact that the C series propellers are about 6 per cent more efficient than the R series might be taken

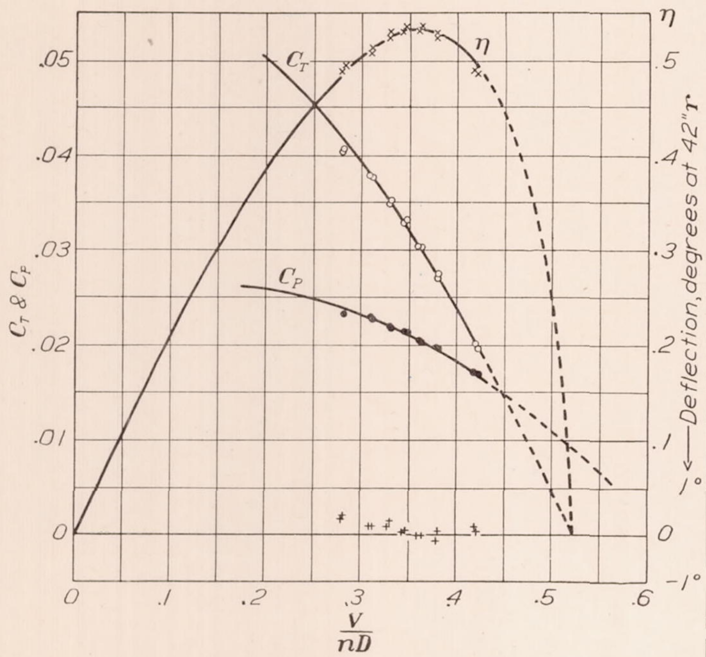


FIGURE 16.—Propeller R–8 set 9.6° at 0.75R. 2,300 r. p. m.

to indicate a superiority of the Clark Y section for propellers. These same propellers have been tested at

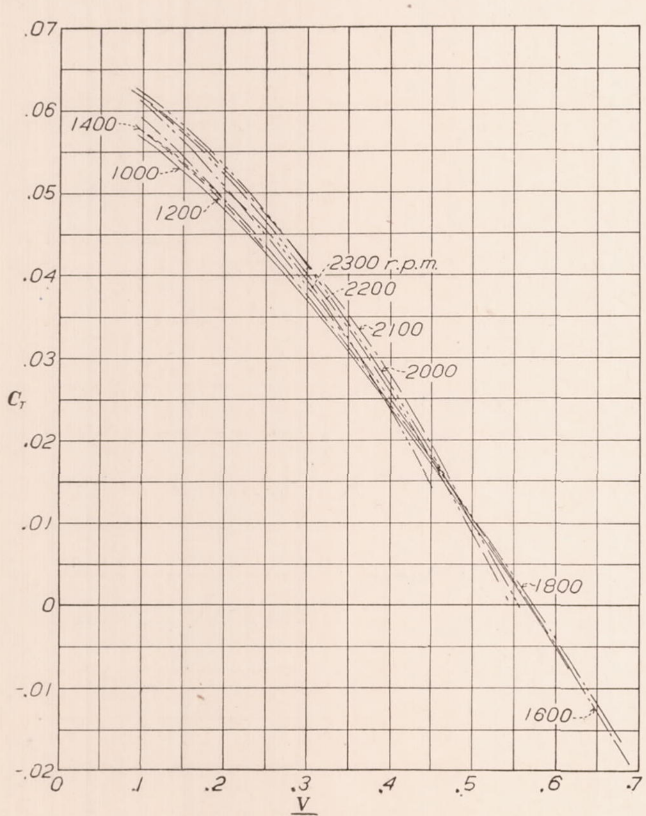


FIGURE 17.—Thrust coefficient vs. $\frac{V}{nD}$. Propeller R–8 set 9.6° at 0.75R.

other pitch settings up to 27° and the data are given in Reference 9. The latter tests show that this advantage for the Clark Y section disappears at the higher pitches where the L/D ratio is a less important factor than it is at lower pitches. In fact the R propellers appear superior at low values of $\frac{V}{nD}$; i. e., high angles of attack of the sections, where the Clark Y section is inferior to the R section.

The standard propellers have a higher efficiency for the narrow than for the wide blades, since the sections of the narrow propellers have somewhat lower thickness ratios than the wide propellers over most of the blade. (Fig. 6.) The tip thickness ratios are higher on the other hand, and the tests show that the efficiency starts to drop at a lower tip speed than for the wide blade with the lower thickness ratio tip. The average thickness ratio of these propellers is about the same as the ratio for the R–6 propeller. The efficiency, as would be expected, is about the same as that of the R–6 at the same setting.

Referring again to the C_T and C_P curves, we note that the speed of change or "critical speed" coincides

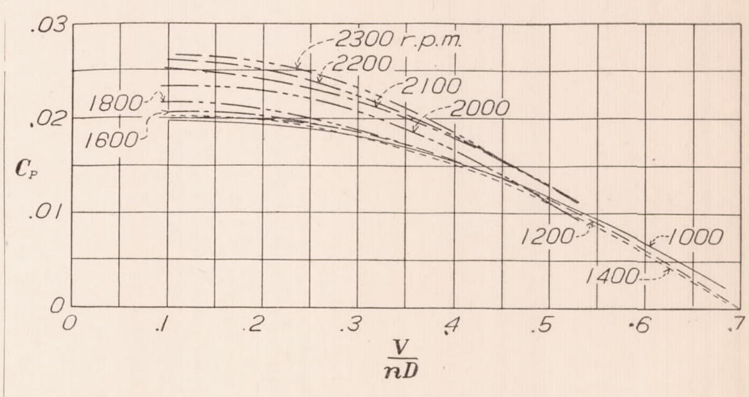


FIGURE 18.—Power coefficient vs. $\frac{V}{nD}$. Propeller R–8 set 9.6° at 0.75R.

with that speed at which C_T begins to drop and C_P to increase rapidly. Above this "critical speed" there is first a gradual drop in efficiency shown by the bend in the curves (figs. 31 to 33, inclusive) and then a rapid drop up to the limit of the tests. Test points were not taken at close enough intervals to establish absolutely the shape of the bend, but there is no reason to suppose that it did not follow the curve through the points.

The constancy of the efficiency up to a certain tip speed suggests the use of a ratio which we shall designate herein "relative efficiency." This is defined as the ratio of the efficiency at any tip speed to the efficiency at tip speeds lower than the "critical speed." Curves of relative efficiency are given at the top of Figures 31 to 33, inclusive. This plotting places the various propellers on a fair basis for comparison; any differences of efficiency that they may have had at low speeds are avoided. The striking feature of these curves is their similar slopes. From these curves one sees that, on the average, the efficiency of the propellers is unaffected by tip speeds of 1,000 feet per second, but that at higher speeds the relative efficiency

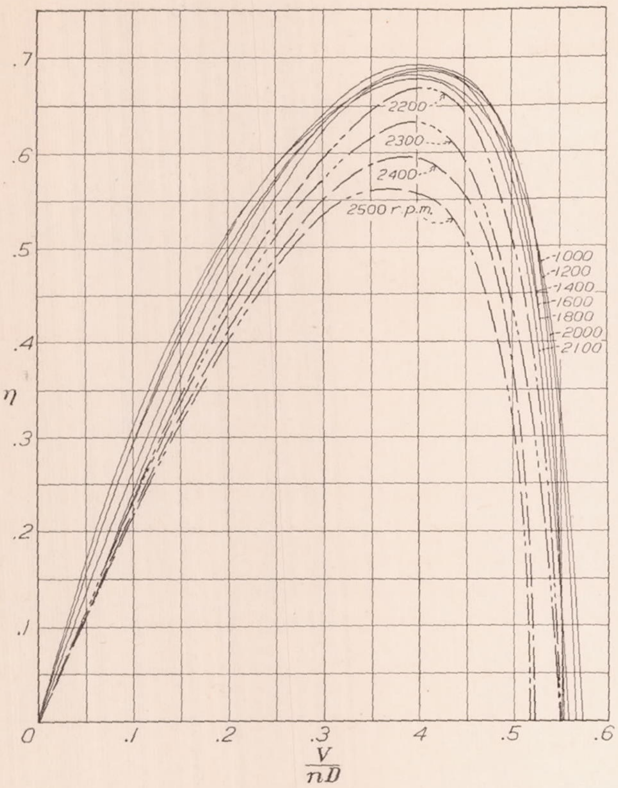


FIGURE 19.—Efficiency vs. $\frac{V}{nD}$. Propeller C-6 set 9.6° at 0.75R.

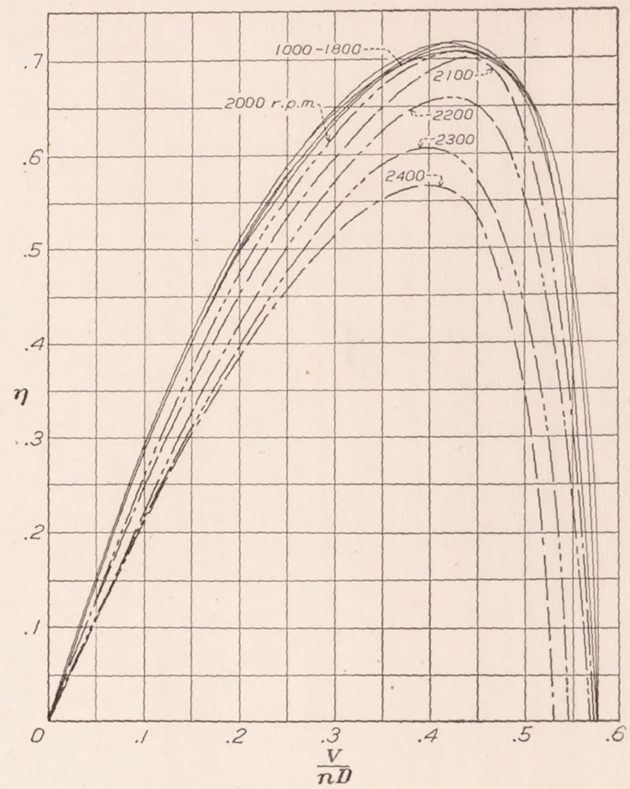


FIGURE 20.—Efficiency vs. $\frac{V}{nD}$. Propeller C-8 set 9.6° at .75R.

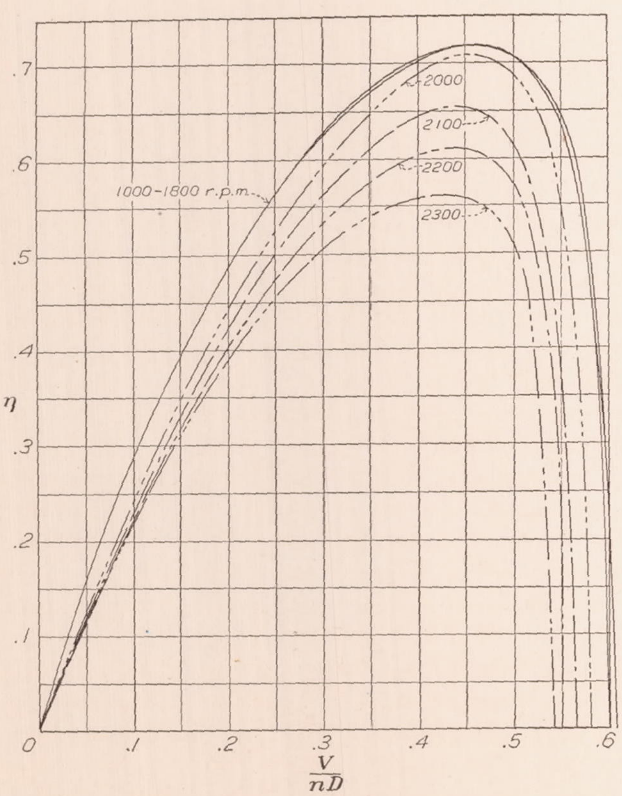


FIGURE 21.—Efficiency vs. $\frac{V}{nD}$. Propeller C-10 set 9.6° at .75R.

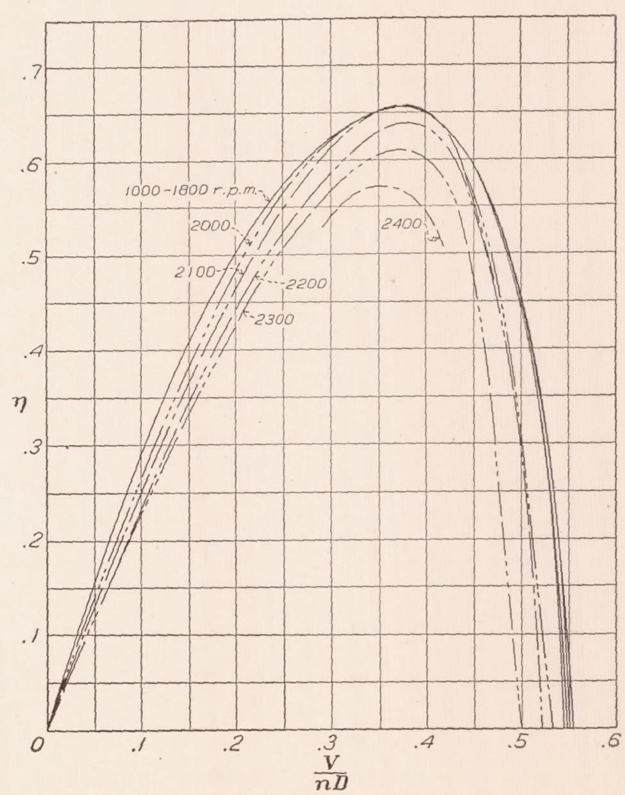


FIGURE 22.—Efficiency vs. $\frac{V}{nD}$. Propeller R-6 set 9.6° at .75R.

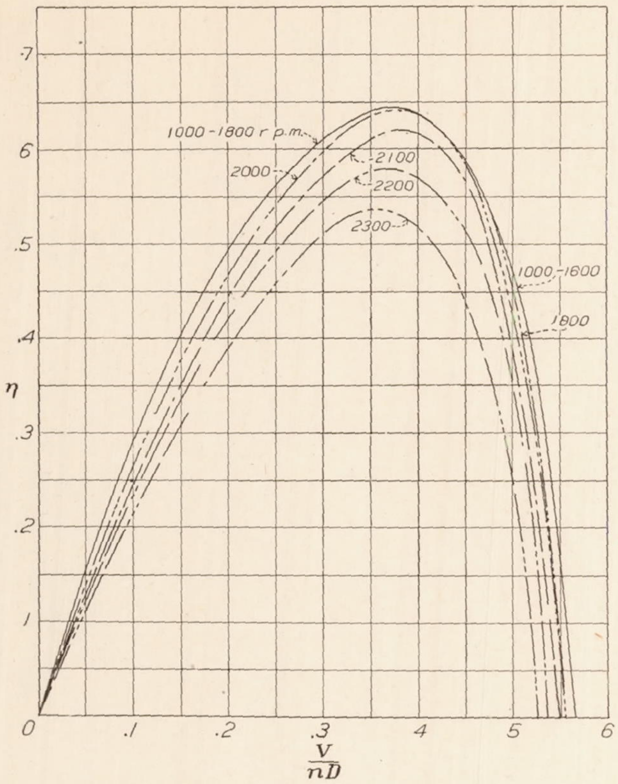


FIGURE 23.—Efficiency vs. $\frac{V}{nD}$. Propeller R-8 set 9.6° at .75R.

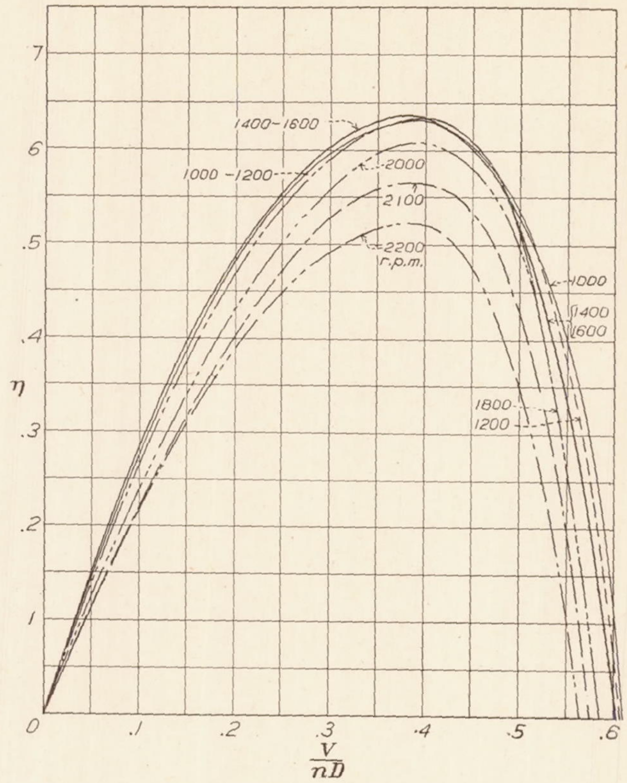


FIGURE 24.—Efficiency vs. $\frac{V}{nD}$. Propeller R-10 set 9.6° at .75R.

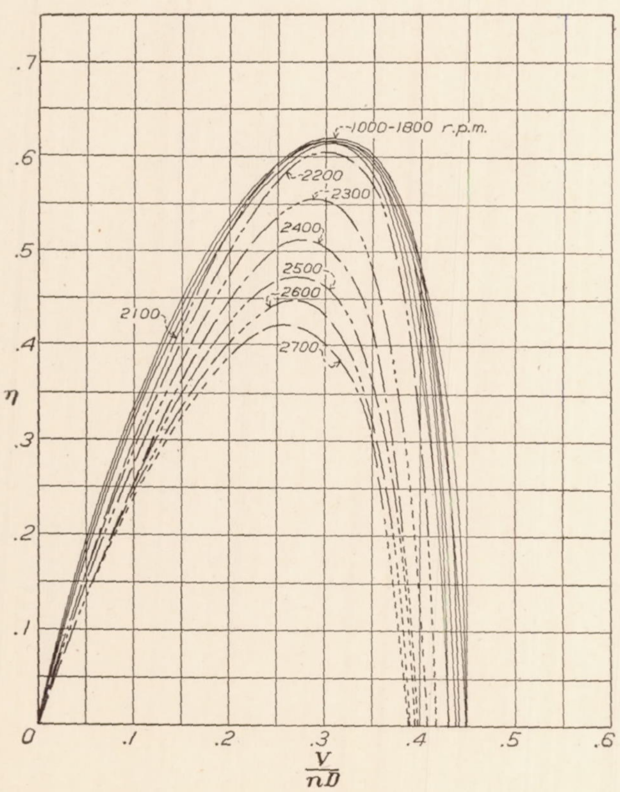


FIGURE 25.—Efficiency vs. $\frac{V}{nD}$. Propeller C-6 set 6.8° at .75R.

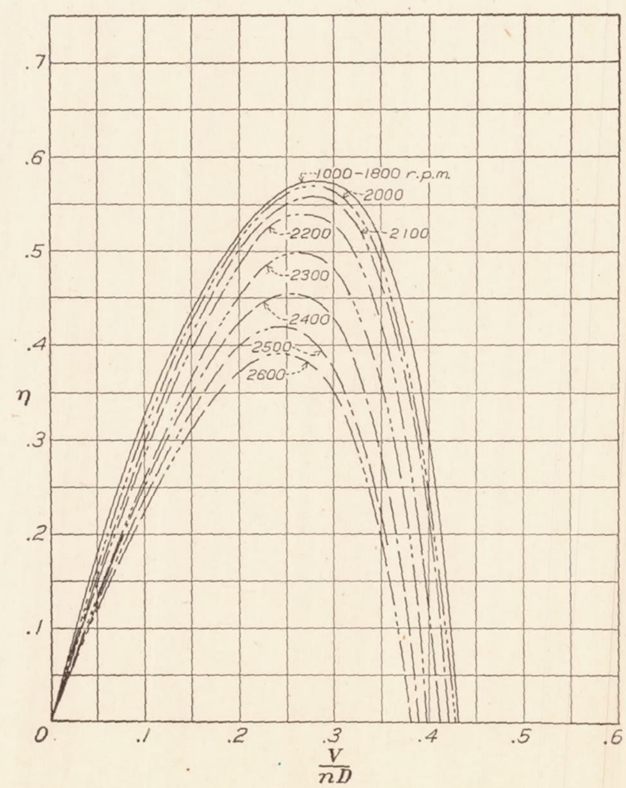


FIGURE 26.—Efficiency vs. $\frac{V}{nD}$. Propeller R-6 set 6.8° at .75R.

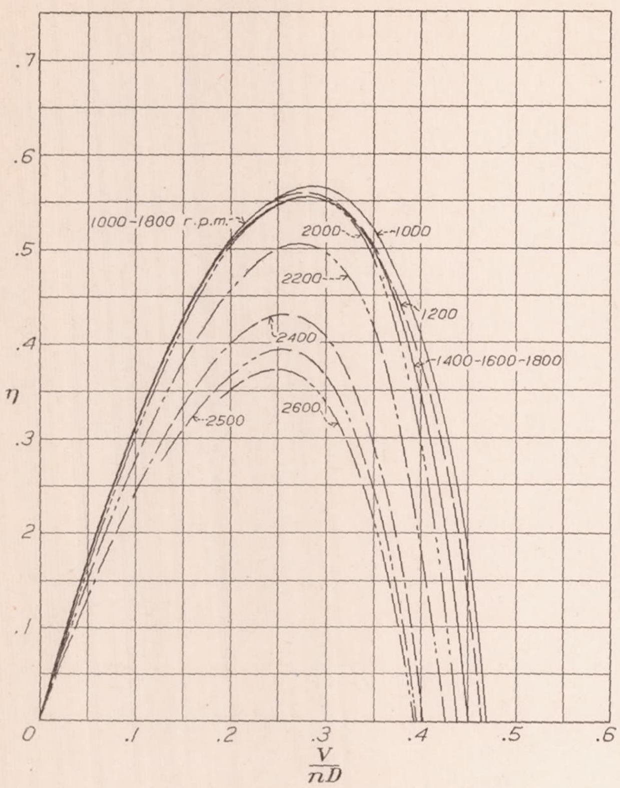


FIGURE 27.—Efficiency vs. $\frac{V}{nD}$. Propeller S-W-9.5 set 6.8° at .75R.

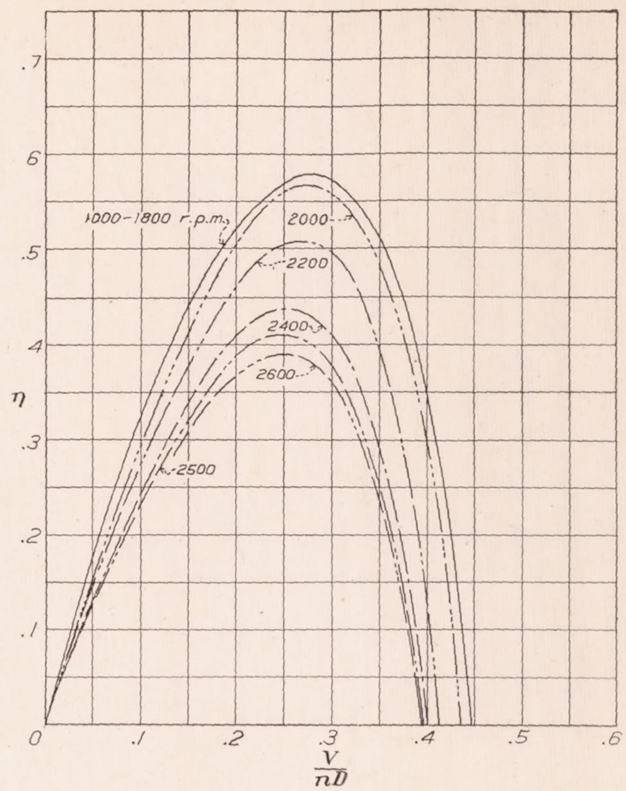


FIGURE 28.—Efficiency vs. $\frac{V}{nD}$. Propeller S-N-9.5 set 6.8° at .75R.

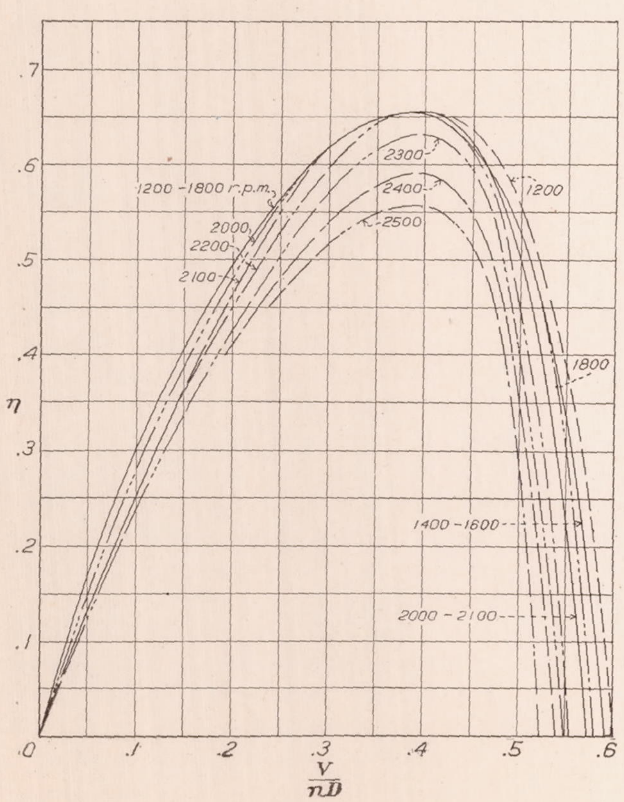


FIGURE 29.—Efficiency vs. $\frac{V}{nD}$. Propeller S-W-9 set 10° at .75R.

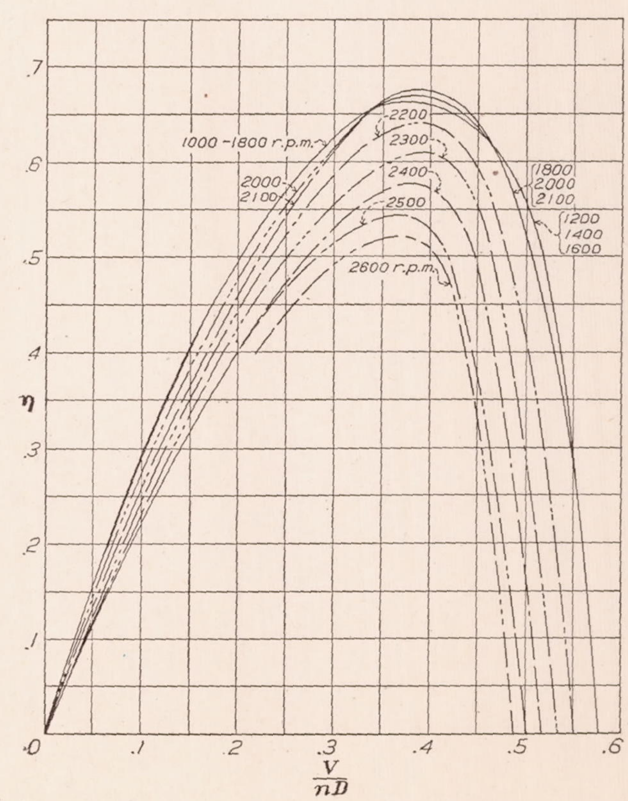


FIGURE 30.—Efficiency vs. $\frac{V}{nD}$. Propeller S-N-9 set 10° at .75R.

drops at a rate of about 10 per cent per an increase of 100 feet per second. These values are easily recalled and agree very well with the facts, but the reader is reminded that they apply only to these low-pitch propellers.

One or two other points are mentioned in passing. The comparisons between the propellers have been

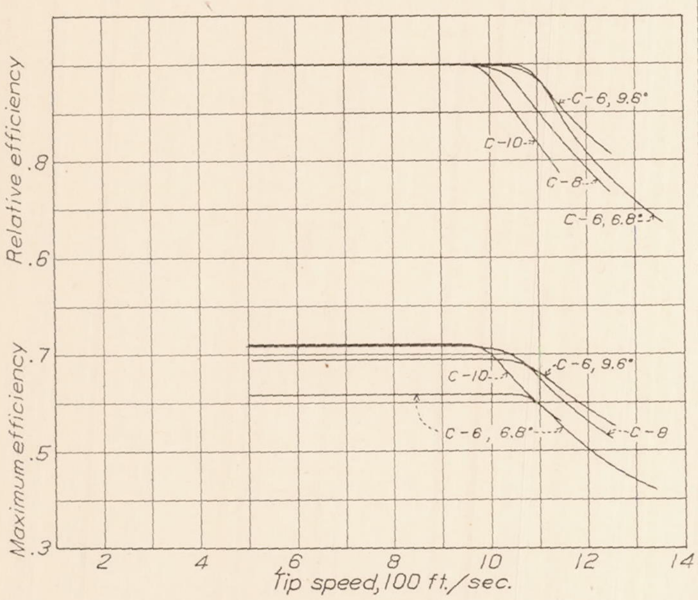


FIGURE 31.—Comparison of maximum efficiencies at various tip speeds. Propeller C-6 set 6.8° and 9.6° at .75*R*. Propellers C-8 and 10 set 9.6° at .75*R*.

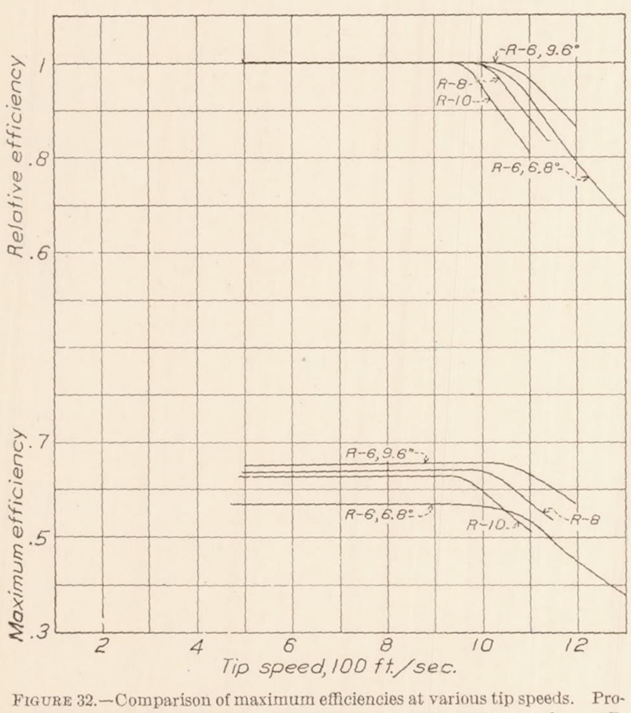


FIGURE 32.—Comparison of maximum efficiencies at various tip speeds. Propeller R-6 set 6.8° and 9.6° at .75*R*. Propellers R-8 and 10 set 9.6° at .75*R*.

made on the basis of "peak" efficiency, since it is one of the most important points of action of the propeller. We also note that this point of maximum efficiency moves to lower values of $\frac{V}{nD}$ as the speed increases. The change in efficiency near the "peak" is so small that a comparison at constant value of $\frac{V}{nD}$ would show the same result as was obtained at the "peak." If comparisons between the propellers are made at lower values of $\frac{V}{nD}$, one will find that similar reductions of efficiency occur, as is evident from the curves. The drop will be somewhat more rapid, because all the efficiency points must gradually converge and reach zero at zero $\frac{V}{nD}$. The values of $\frac{V}{nD}$ above peak efficiency are of little practical importance. Any comparisons here are likely to be erratic because of the rapid change in efficiency with change of $\frac{V}{nD}$. In the

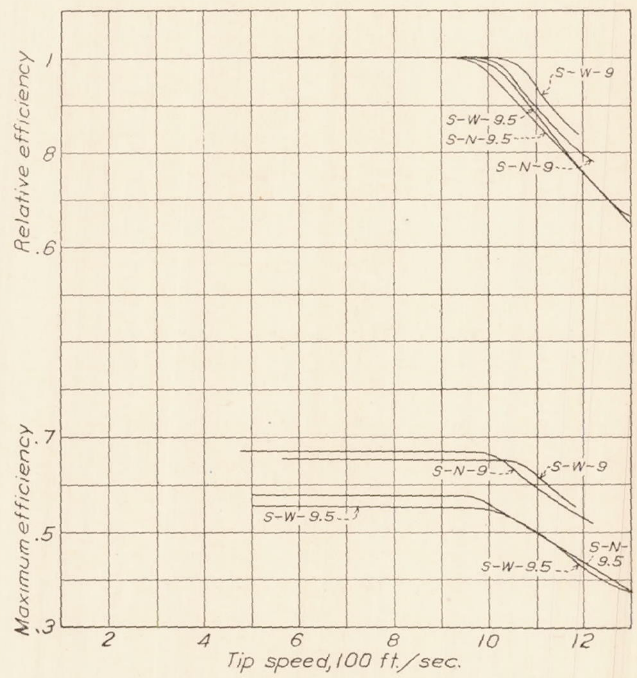


FIGURE 33.—Comparison of maximum efficiencies at various tip speeds. Propellers S-9.5 set 6.8° at .75*R*. Propellers S-9 set 10° at .75*R*.

case of a plane diving at high speed, the decrease in dynamic pitch and small increase in power at the higher speeds indicate that a higher negative thrust may be expected than one would estimate from the results of low tip speed tests.

A phenomenon of little importance in the measurements, but of great practical importance, is the production of noise. Even with the confining and damping action of the walls of the large tunnel building, the noise at speeds above 1,000 feet per second was disagreeable more than half a mile away, and could be heard more than a mile and a half away. Within the test chamber a most penetrating sound prevailed, which could not be rendered agreeable by any known methods or by new ones devised for the occasion. The whole structure vibrated, effectively shaking down any dust and loosening all insecure parts. The observers noticed, however, that the cockpit was the least objectionable location and any point in the plane of the

propeller and ahead of it, the worst. A change in the characteristic roar of the engine and swish of the propeller appeared quite suddenly at about the "critical speed." At higher speeds a high-pitched unearthly whine prevailed. This fact indicated that the speed at which the efficiency begins to drop can be predicted quite closely from this change in the characteristic sound. A study of the problem of noise is now being made at this laboratory with a view to isolating the predominant frequencies and developing means for their elimination.

Theoretical discussions of compressibility involve the velocity of sound in air. At this velocity complications appear in the usual theory. In fact, it is commonly supposed that the velocity of sound is the critical point in the speed of bodies. This is about 1,115 feet per second at 60° F. The fact that the test results show a lower "critical speed" (950 feet to 1,050 feet per second) is explained by the circumstance that there are points in the fluid, over the top of the blades, where the velocity is greater than the relative velocity between the free air and propeller tips, on which our calculations are based. This conclusion is substantiated by the fact that the thick propellers which have the highest intake velocities also have the lowest "critical speed."

Finally, the results of these tests confirm those of the earlier full-scale tests of Reference 6 so far as the latter apply. They also agree qualitatively with the results of the airfoil tests of References 2 to 5, inclusive; namely, that thin sections are less affected by high speeds. These airfoil tests also indicate that at high speeds a section in the shape of a circular segment is superior to others. The agreement between results of the tests of the standard sections and the propeller test results leads to the conclusion that there might be some advantage in building a propeller with sections which are segments of circles near the tips, gradually running into standard sections along the blades. It is hoped to take this matter up in later tests.

Most of the practical questions concerning high-tip-speed propellers are answered by these tests, since they were made under full-scale conditions. Their lack of agreement with the results of model tests may be traced to the fact that the importance of scale increases at very high speeds.

The question may arise, "Are the results of these tests with low pitch diameter ratios applicable to propellers of the pitches normally used?" While the low pitches and velocities were, unfortunately, made necessary by the limitations of wind tunnel equipment, clearly the high relative velocities of propeller and air were actually obtained. It is to be expected that, near maximum efficiency, the angles of attack of most of the sections of a propeller will be about the same, whatever the pitch. The classical Drzewiecki blade-element theory of propellers shows that the ideal efficiency of a propeller section is

$$\eta=\frac{\tan\Phi}{\tan\ (\Phi+\gamma)}$$

where

$$\Phi=\tan^{-1}\frac{V}{2\pi\ r\ n}$$

$$\gamma=\tan^{-1}\frac{\text{drag}}{\text{lift}}$$

r = radius of the section

By substituting in this equation the measured values of efficiency η and the values of Φ computed from the values of $\frac{V}{nD}$, values of γ can be obtained. On the assumption that, at maximum efficiency, angles of attack are constant for all pitches, these values of γ will apply to other pitches. By substituting these values of γ and new values of Φ a table can be prepared or curves plotted showing the value of efficiency for any pitch at any tip speed. This computation is but slightly modified by the later vortex theory of Glauert. Other ways of making this transfer to other pitches may suggest themselves to individual designers.

The most reasonable conclusion developed from these tests is that high tip speeds are to be avoided; first, because of the disagreeable physiological effects, and second, because of the lowered efficiency. Since noise is one of the serious problems of aeronautics, energetic efforts are being made to reduce or eliminate it. Attempts to reduce the noise of high-speed propellers promise little success. With the increase in the number of geared engines driving large slow propellers the advantages of high pitch as well as lower speed are realized. There will still be some use of high-tip-speed propellers and the data at hand will be useful in the analysis and design of such types.

CONCLUSIONS

1. The efficiency of standard metal propellers is practically unaffected by tip speed up to 1,000 feet per second.

2. Above a tip speed of 1,000 feet per second, the efficiency, relative to that at lower speeds, falls off; for propellers of low pitch (6.8° and 9.6° at $0.75R$), at a rate of about 10 per cent per 100 feet per second increase.

3. Propellers with low thickness ratio tips can be operated at slightly higher tip speeds than thick tip propellers without loss of efficiency.

4. Tip speeds approaching the velocity of sound, or above it, are to be avoided not only because of the loss of efficiency, but because of the disagreeable sound at these high speeds.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *November 5, 1930.*

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TABLE I

FINAL ADJUSTED COEFFICIENTS

PROPELLER C-6 SET 9.6° AT 0.75*R*

1,000 r. p. m.				1,200 r. p. m.			
$\frac{V}{nD}$	C_T	C_P	η	$\frac{V}{nD}$	C_T	C_P	η
0.10	0.0580	0.0190	0.305	0.10	0.0547	0.0185	0.296
.15	.0530	.0190	.419	.15	.0509	.0184	.415
.20	.0476	.0186	.512	.20	.0462	.0180	.513
.25	.0420	.0180	.585	.25	.0409	.0174	.587
.30	.0363	.0171	.637	.30	.0349	.0165	.635
.35	.0298	.0156	.669	.35	.0284	.0149	.667
.40	.0230	.0134	.686	.40	.0219	.0129	.680
.45	.0164	.0111	.675	.45	.0153	.0103	.668
.50	.0098	.00825	.595	.50	.0088	.0075	.586
1,400 r. p. m.				**1,600 r. p. m.**			
0.10	0.056	0.0186	0.302	0.10	0.0583	0.0197	0.296
.15	.0516	.0186	.418	.15	.0535	.0195	.412
.20	.0474	.0184	.515	.20	.0480	.0189	.508
.25	.0413	.0177	.583	.25	.0416	.0180	.578
.30	.0348	.0164	.638	.30	.0350	.0166	.633
.35	.0273	.0147	.675	.35	.0285	.0148	.674
.40	.0217	.0126	.690	.40	.0216	.0125	.691
.45	.0154	.0103	.672	.45	.0149	.0099	.677
.50	.00845	.00704	.600	.50	.0078	.0065	.595
1,800 r. p. m.				**2,000 r. p. m.**			
0.10	0.0607	0.0208	0.292	0.10	0.0617	0.0229	0.270
.15	.0553	.0203	.408	.15	.0575	.0223	.387
.20	.0493	.0196	.503	.20	.0524	.0214	.490
.25	.0430	.0185	.580	.25	.0457	.0200	.570
.30	.0362	.0170	.638	.30	.0382	.0182	.630
.35	.0294	.0152	.678	.35	.0312	.0163	.670
.40	.0224	.0129	.692	.40	.0238	.0137	.695
.45	.0153	.0102	.676	.45	.0162	.0107	.682
.50	.0077	.0067	.575	.50	.0085	.0070	.606
2,100 r. p. m.				**2,200 r. p. m.**			
0.10	0.0612	0.0253	0.242	0.10	0.0605	0.0255	0.237
.15	.0598	.0247	.364	.15	.0587	.0252	.350
.20	.0550	.0235	.469	.20	.0543	.0241	.450
.25	.0478	.0215	.556	.25	.0472	.0222	.532
.30	.0400	.0192	.625	.30	.0397	.0199	.598
.35	.0324	.0170	.668	.35	.0323	.0125	.648
.40	.0244	.0144	.680	.40	.0246	.0147	.670
.45	.0170	.0117	.654	.45	.0165	.0115	.645
.50	.0097	.0088	.550	.50	.0081	.0080	.505

TABLE I—Continued

FINAL ADJUSTED COEFFICIENTS—Continued

PROPELLER C-6 SET 9.6° AT 0.75*R*—Continued

2,300 r. p. m.							
$\frac{V}{nD}$	C_T	C_P	η	$\frac{V}{nD}$	C_T	C_P	η
0.20	0.0522	0.0242	0.432				
.25	.0470	.0228	.515				
.30	.0398	.0208	.573				
.35	.0320	.0182	.616				
.40	.0237	.0150	.633				
.45	.0156	.0118	.594				

PROPELLER C-8 SET 9.6° AT 0.75*R*

1,000 r. p. m.				1,200 r. p. m.			
0.10	0.0555	0.0189	0.294	0.10	0.0567	0.0194	0.292
.15	.0508	.0188	.4055	.15	.0535	.0194	.413
.20	.0459	.0185	.495	.20	.0490	.0192	.510
.25	.0410	.0180	.570	.25	.0437	.0186	.587
.30	.0359	.0171	.630	.30	.0375	.0175	.643
.35	.0304	.0157	.678	.35	.0314	.0160	.688
.40	.0247	.0139	.711	.40	.0250	.0140	.713
.45	.0185	.0118	.705	.45	.0181	.0115	.707
.50	.0120	.0090	.666	.50	.0110	.0082	.670
.55	.0044	.0051	.475	.55	.0041	.0048	.470
1,400 r. p. m.				**1,600 r. p. m.**			
0.10	0.0583	0.0197	0.296	0.10	0.0601	0.0205	0.293
.15	.0545	.0196	.417	.15	.0556	.0205	.407
.20	.0493	.0192	.514	.20	.0506	.0201	.504
.25	.0437	.0186	.587	.25	.0445	.0192	.580
.30	.0378	.0176	.645	.30	.0380	.0178	.640
.35	.0313	.0160	.685	.35	.0314	.0161	.682
.40	.0248	.0140	.706	.40	.0247	.0139	.710
.45	.0177	.0113	.705	.45	.0177	.0112	.709
.50	.0107	.0081	.660	.50	.0105	.0080	.658
.55	.0037	.0043	.475	.55	.0033	.0040	.455
1,800 r. p. m.				**2,000 r. p. m.**			
0.10	0.0618	0.0217	0.285	0.10	0.0617	0.0241	0.256
.15	.0571	.0213	.403	.15	.0585	.0237	.370
.20	.0515	.0205	.502	.20	.0538	.0229	.470
.25	.0455	.0196	.580	.25	.0477	.0217	.550
.30	.0388	.0183	.636	.30	.0412	.0200	.617
.35	.0321	.0165	.682	.35	.0340	.0177	.672
.40	.0251	.0141	.712	.40	.0261	.0149	.701
.45	.0181	.0114	.713	.45	.0187	.0119	.707
.50	.0110	.0082	.668	.50	.0112	.0085	.657
.55	.0049	.0037	.400	.55	.0037	.0046	.445
2,100 r. p. m.				**2,200 r. p. m.**			
0.10	0.0630	0.0256	0.246	0.10	0.0602	0.0266	0.226
.15	.0590	.0250	.354	.15	.0575	.0261	.330
.20	.0540	.0240	.450	.20	.0530	.0251	.422
.25	.0480	.0228	.527	.25	.0475	.0235	.505
.30	.0415	.0211	.590	.30	.0410	.0216	.570
.35	.0347	.0189	.643	.35	.0341	.0191	.625
.40	.0274	.0160	.687	.40	.0266	.0163	.654
.45	.0200	.0130	.700	.45	.0190	.0131	.652
.50	.0120	.0095	.631	.50	.0107	.0097	.550
.55	.0035	.0058	.332	.55	.0027	.0060	.250
2,300 r. p. m.				**2,400 r. p. m.**			
0.10	0.0560	0.0267	0.210	0.10	0.0580	0.0278	0.209
.15	.0540	.0265	.305	.15	.0550	.0276	.299
.20	.0508	.0258	.394	.20	.0510	.0269	.380
.25	.0466	.0247	.472	.25	.0460	.0253	.454
.30	.0410	.0228	.539	.30	.0396	.0232	.511
.35	.0341	.0204	.585	.35	.0324	.0205	.552
.40	.0256	.0169	.606	.40	.0240	.0170	.565
.45	.0170	.0133	.572	.45	.0155	.0130	.535
.50	.0085	.0095	.445	.50	.0061	.0086	.356
.55	.000	.0055	.00	.55	----------	.0037	----------
2,500 r. p. m.							
0.10	0.0570	0.0294	0.192				
.15	.0540	.0290	.279				
.20	.0497	.0280	.355				
.25	.0445	.0263	.422				
.30	.0383	.0241	.477				
.35	.0311	.0211	.516				
.40	.0232	.0176	.527				
.45	.0147	.0136	.486				
.50	.0051	.0090	.284				
.55	----------	.0043	----------				

TABLE I—Continued

FINAL ADJUSTED COEFFICIENTS—Continued

PROPELLER C-10 SET 9.6° AT 0.75R

1,000 r. p. m.				1,200 r. p. m.			
$\frac{V}{nD}$	C_T	C_P	η	$\frac{V}{nD}$	C_T	C_P	η
0.10	0.0616	0.0216	0.285	0.10	0.0607	0.0214	0.283
.15	.0565	.0216	.392	.15	.0564	.0216	.392
.20	.051	.021	.485	.20	.0516	.0214	.483
.25	.0455	.0202	.562	.25	.0463	.0205	.564
.30	.0397	.0190	.626	.30	.0408	.0195	.627
.35	.0336	.0175	.674	.35	.0347	.0180	.673
.40	.0277	.0150	.707	.40	.0285	.0162	.705
.45	.0217	.0136	.720	.45	.0222	.0139	.72
.50	.0150	.0106	.710	.50	.0160	.0113	.708
.55	--------	--------	.640	.55	.0098	.00752	.65

1,400 r. p. m.				1,600 r. p. m.			
0.10	0.0609	0.0213	0.285	0.10	0.0635	0.0218	0.291
.15	.0570	.0218	.392	.15	.0580	.0218	.397
.20	.0525	.0216	.485	.20	.0525	.0215	.487
.25	.0470	.0208	.565	.25	.0469	.0207	.566
.30	.0410	.0195	.628	.30	.0412	.0196	.628
.35	.0347	.0180	.675	.35	.0350	.0181	.675
.40	.0282	.0160	.707	.40	.0285	.0162	.706
.45	.0215	.0135	.72	.45	.0222	.0139	.720
.50	.0146	.0103	.708	.50	.0155	.0109	.710
.55	.0068	.0080	.65	.55	.0084	.0073	.633

1,800 r. p. m.				2,000 r. p. m.			
0.10	0.0665	0.0238	0.279	0.10	0.0609	0.0256	0.238
.15	.061	.0235	.389	.15	.0583	.0252	.347
.20	.0552	.0228	.484	.20	.0545	.0247	.442
.25	.049	.0217	.565	.25	.0498	.0237	.525
.30	.0427	.0204	.627	.30	.0442	.0224	.591
.35	.0362	.0188	.675	.35	.0382	.0206	.647
.40	.0295	.0167	.706	.40	.0313	.0181	.690
.45	.0230	.0144	.720	.45	.0232	.0147	.710
.50	.0155	.0109	.71	.50	.0147	.0107	.686
.55	.0080	.0068	.647	.55	.0059	.0060	.538

2,100 r. p. m.				2,200 r. p. m.			
0.10	0.06	0.0265	0.226	0.10	0.062	0.0278	0.223
.15	.0572	.0262	.328	.15	.0578	.0272	.319
.20	.0535	.0254	.421	.20	.0530	.0262	.405
.25	.0490	.0244	.502	.25	.0475	.0251	.472
.30	.0435	.0232	.563	.30	.0417	.0236	.534
.35	.0371	.0213	.609	.35	.0354	.0215	.575
.40	.0304	.0188	.647	.40	.0284	.0187	.605
.45	.0230	.0158	.655	.45	.0208	.0153	.610
.50	.0150	.0122	.615	.50	.0123	.0107	.574
.55	.005	.0075	.367				

2,300 r. p. m.			
0.10	0.0605	0.0275	0.22
.15	.0567	.0274	.31
.20	.0517	.0267	.387
.25	.0462	.0258	.455
.30	.0405	.0242	.505
.35	.0340	.022	.54
.40	.0274	.0193	.558
.45	.0190	.0151	.558
.50	.01	.0098	.51

PROPELLER R-6 SET 9.6° AT 0.75R

1,000 r. p. m.				1,200 r. p. m.			
0.10	0.0534	0.0179	0.298	0.10	0.0543	0.0184	0.296
.15	.0487	.0179	.408	.15	.0495	.0182	.408
.20	.0440	.0175	.502	.20	.0441	.0176	.501
.25	.0384	.0167	.575	.25	.0385	.01675	.575
.30	.0329	.0158	.625	.30	.0328	.0156	.626
.35	.0270	.0146	.648	.35	.0270	.0145	.650
.40	.0210	.0130	.647	.40	.0211	.0129	.654
.45	.0147	.0111	.595	.45	.0145	.0110	.593
.50	.0081	.0089	.455	.50	.0077	.0086	.450

TABLE I—Continued

FINAL ADJUSTED COEFFICIENTS—Continued

PROPELLER R-6 SET 9.6° AT 0.75R—Continued

1,400 r. p. m.				1,600 r. p. m.			
$\frac{V}{nD}$	C_T	C_P	η	$\frac{V}{nD}$	C_T	C_P	η
0.10	0.0556	0.0187	0.297	0.10	0.0568	0.0192	0.296
.15	.0505	.0185	.409	.15	.0517	.0190	.409
.20	.0449	.0179	.502	.20	.0460	.0183	.503
.25	.0392	.0170	.576	.25	.0402	.0174	.577
.30	.0330	.0159	.622	.30	.0342	.0164	.625
.35	.0268	.0145	.647	.35	.0278	.0150	.649
.40	.0208	.0129	.645	.40	.0215	.0133	.646
.45	.0142	.0108	.592	.45	.0147	.0111	.595
.50	.0075	.0083	.452	.50	.0076	.0084	.453

1,800 r. p. m.				2,000 r. p. m.			
0.10	0.0583	0.0198	0.295	0.10	0.0610	0.0228	0.268
.15	.0531	.0196	.407	.15	.0563	.0221	.382
.20	.0476	.0191	.500	.20	.0507	.0210	.484
.25	.0414	.0180	.575	.25	.0442	.0195	.566
.30	.0351	.0169	.623	.30	.0371	.0179	.621
.35	.0285	.0153	.651	.35	.0300	.0161	.652
.40	.0217	.0134	.647	.40	.0227	.0139	.653
.45	.0145	.0111	.588	.45	.0146	.0112	.558
.50	.0073	.0084	.435	.50	.0053	.0089	.300

2,100 r. p. m.				2,200 r. p. m.			
0.10	0.0605	0.0240	0.252	0.10	0.0611	0.0259	0.236
.15	.0570	.0236	.362	.15	.0576	.0250	.346
.20	.0525	.0226	.465	.20	.0523	.0235	.445
.25	.0463	.0211	.548	.25	.0459	.0219	.524
.30	.0393	.0192	.614	.30	.0389	.0199	.586
.35	.0315	.0169	.652	.35	.0315	.0175	.630
.40	.0232	.0142	.653	.40	.0235	.0148	.635
.45	.0142	.0113	.565	.45	.0143	.0119	.540
.50	.0050	.0082	.305	.50	.0050	.0085	.294

2,300 r. p. m.				2,400 r. p. m.			
0.10	0.0593	0.0259	0.229	0.30	0.0377	0.0210	0.539
.15	.0557	.0251	.333	.35	.0296	.0181	.572
.20	.0511	.0240	.426	.40	.0201	.0148	.543
.25	.0456	.0225	.507				
.30	.0390	.0206	.568				
.35	.0315	.0182	.606				
.40	.0225	.0150	.600				
.45	.0120	.0113	.478				

PROPELLER R-8 SET 9.6° AT 0.75R

1,000 r. p. m.				1,200 r. p. m.			
0.10	0.0565	0.0198	0.285	0.10	0.0572	0.0200	0.286
.15	.0524	.0195	.403	.15	.0535	.0199	.403
.20	.0476	.0193	.492	.20	.0489	.0198	.493
.25	.0424	.0190	.559	.25	.0434	.0194	.559
.30	.0367	.0181	.608	.30	.0373	.0184	.607
.35	.0305	.0167	.639	.35	.0309	.0170	.636
.40	.0242	.0152	.636	.40	.0244	.0154	.634
.45	.0177	.0137	.583	.45	.0175	.0135	.584
.50	.0108	.0115	.472	.50	.0106	.0113	.470

1,400 r. p. m.				1,600 r. p. m.			
0.10	0.0575	0.0202	0.285	0.10	0.0590	0.0208	0.284
.15	.0534	.0200	.401	.15	.0545	.0205	.400
.20	.0484	.0196	.494	.20	.0491	.0200	.491
.25	.0428	.0191	.560	.25	.0430	.0192	.560
.30	.0368	.0181	.610	.30	.0367	.0181	.608
.35	.0307	.0169	.636	.35	.0305	.0168	.636
.40	.0241	.0152	.634	.40	.0238	.0150	.635
.45	.0173	.0134	.581	.45	.0170	.0132	.580
.50	.0103	.0110	.470	.50	.0102	.0108	.472

1,800 r. p. m.				2,000 r. p. m.			
0.10	0.0610	0.0216	0.282	0.10	0.0620	0.0234	0.265
.15	.0564	.0214	.396	.15	.0580	.0232	.375
.20	.0506	.0208	.488	.20	.0530	.0227	.467
.25	.0444	.0198	.560	.25	.0474	.0220	.538
.30	.0382	.0188	.609	.30	.0410	.0207	.594
.35	.0316	.0173	.639	.35	.0339	.0188	.632
.40	.0247	.0155	.636	.40	.0263	.0166	.634
.45	.0173	.0134	.581	.45	.0181	.0140	.581
.50	.0100	.0110	.455	.50	.0097	.0113	.430

TABLE I—Continued

FINAL ADJUSTED COEFFICIENTS—Continued

PROPELLER R-8 SET 9.6° AT 0.75R—Continued

2,100 r. p. m.				2,200 r. p. m.			
$\frac{V}{nD}$	C_T	C_P	η	$\frac{V}{nD}$	C_T	C_P	η
0.10	0.0615	0.0251	0.245	0.10	0.0614	0.0260	0.236
.15	.0576	.0247	.350	.15	.0572	.0258	.333
.20	.0530	.0240	.442	.20	.0523	.0250	.419
.25	.0471	.0220	.515	.25	.0464	.0238	.487
.30	.0412	.0218	.568	.30	.0400	.0222	.541
.35	.0350	.0202	.606	.35	.0332	.0202	.575
.40	.0276	.0180	.615	.40	.0256	.0180	.568
.45	.0195	.0155	.565	.45	.0177	.0154	.518
.50	.0101	.0129	.392	.50	.0089	.0124	.359

2,300 r. p. m.			
0.20	0.0501	0.0259	0.387
.25	.0451	.0248	.455
.30	.0390	.0232	.504
.35	.0321	.0211	.533
.40	.0238	.0184	.516
.45	.0145	.0149	.437

PROPELLER R-10 SET 9.6° AT 0.75R

1,000 r. p. m.				1,200 r. p. m.			
0.10	0.0604	0.0216	0.279	0.10	0.0608	0.0219	0.278
.15	.0559	.0214	.391	.15	.0562	.0216	.391
.20	.0507	.0211	.480	.20	.0510	.0213	.480
.25	.0453	.0207	.547	.25	.0456	.0208	.547
.30	.0397	.0200	.595	.30	.0401	.0202	.595
.35	.0342	.0192	.623	.35	.0347	.0195	.624
.40	.0283	.0180	.629	.40	.0292	.0186	.629
.45	.0221	.0166	.599	.45	.0230	.0172	.600
.50	.0160	.0150	.523	.50	.0163	.0152	.536

1,400 r. p. m.				1,600 r. p. m.			
0.10	0.0605	0.0214	0.282	0.10	0.0610	0.0216	0.282
.15	.0562	.0213	.396	.15	.0570	.0215	.396
.20	.0515	.0211	.489	.20	.0523	.0214	.489
.25	.0460	.0208	.552	.25	.0469	.0212	.552
.30	.0407	.0204	.600	.30	.0410	.0205	.600
.35	.0350	.0195	.628	.35	.0350	.0195	.628
.40	.0286	.0181	.632	.40	.0285	.0182	.632
.45	.0217	.0163	.600	.45	.0220	.0165	.600
.50	.0149	.0145	.513	.50	.0155	.0150	.515

1,800 r. p. m.				2,000 r. p. m.			
0.10	0.0634	0.0238	0.266	0.10	0.0630	0.0263	0.240
.15	.0592	.0236	.376	.15	.0589	.0259	.341
.20	.0543	.0232	.468	.20	.0541	.0252	.430
.25	.0486	.0225	.540	.25	.0489	.0243	.503
.30	.0426	.0217	.589	.30	.0433	.0233	.556
.35	.0363	.0204	.622	.35	.0375	.0220	.596
.40	.0297	.0188	.631	.40	.0308	.0203	.606
.45	.0230	.0170	.609	.45	.0235	.0183	.578
.50	.0151	.0150	.504	.50	.0160	.0161	.497

2,100 r. p. m.				2,200 r. p. m.			
0.10	0.0616	0.0276	0.224	0.10	0.0587	0.0272	0.216
.15	.0581	.0273	.320	.15	.0554	.0268	.309
.20	.0537	.0267	.402	.20	.0511	.0264	.387
.25	.0487	.0256	.476	.25	.0461	.0257	.449
.30	.0429	.0242	.531	.30	.0404	.0247	.490
.35	.0364	.0229	.556	.35	.0340	.0231	.515
.40	.0298	.0212	.562	.40	.0268	.0207	.518
.45	.0226	.0191	.532	.45	.0191	.0183	.470
.50	.0144	.0169	.426	.50	.0108	.0156	.346

PROPELLER C-6 SET 6.8° AT 0.75R

1,000 r. p. m.				1,200 r. p. m.			
0.10	0.0406	0.0127	0.320	0.10	0.0412	0.0124	0.332
.15	.0363	.0126	.432	.15	.0358	.0121	.443
.20	.0315	.0121	.521	.20	.0308	.0116	.530
.25	.0262	.0112	.585	.25	.0254	.0108	.588
.30	.0203	.0099	.615	.30	.0196	.0096	.615
.35	.0140	.0082	.598	.35	.0134	.0079	.593
.40	.0074	.0061	.485	.40	.0066	.0055	.479

TABLE I—Continued

FINAL ADJUSTED COEFFICIENTS—Continued

PROPELLER C-6 SET 6.8° AT 0.75R—Continued

1,400 r. p. m.				1,600 r. p. m.			
$\frac{V}{nD}$	C_T	C_P	η	$\frac{V}{nD}$	C_T	C_P	η
0.10	0.0414	0.0126	0.328	0.10	0.0417	0.0129	0.324
.15	.0367	.0124	.444	.15	.0368	.0125	.441
.20	.0313	.0118	.530	.20	.0315	.0120	.531
.25	.0257	.0109	.590	.25	.0257	.0109	.590
.30	.0195	.0095	.615	.30	.0194	.0094	.619
.35	.0128	.0076	.590	.35	.0127	.0074	.600
.40	.0060	.0051	.471	.40	.0057	.0048	.475

1,800 r. p. m.				2,000 r. p. m.			
0.10	0.0423	0.0132	0.321	0.10	0.0452	0.0142	0.318
.15	.0377	.0129	.438	.15	.0398	.0136	.438
.20	.0324	.0122	.531	.20	.0339	.0128	.530
.25	.0261	.0111	.589	.25	.0271	.0115	.590
.30	.0196	.0096	.612	.30	.0198	.0097	.613
.35	.0125	.0075	.584	.35	.0125	.0075	.583
.40	.00525	.0048	.437	.40	.0047	.0048	.390

2,100 r. p. m.				2,200 r. p. m.			
0.10	0.0471	0.0155	0.304	0.10	0.0464	0.0159	0.292
.15	.0414	.0146	.425	.15	.0416	.0153	.408
.20	.0352	.0134	.525	.20	.0355	.0141	.504
.25	.0282	.0119	.593	.25	.0286	.0124	.576
.30	.0204	.0099	.618	.30	.0209	.0104	.603
.35	.0127	.0075	.590	.35	.0126	.0078	.565
.40	.0047	.0048	.392	.40	.0035	.00485	.289

2,300 r. p. m.				2,400 r. p. m.			
0.10	0.0469	0.0171	0.274	0.10	0.0470	0.0183	0.255
.15	.0418	.0163	.384	.15	.0418	.0172	.365
.20	.0355	.0150	.474	.20	.0352	.0156	.451
.25	.0279	.0130	.536	.25	.0272	.0135	.503
.30	.0197	.0107	.552	.30	.0185	.0110	.504
.35	.0110	.0080	.480	.35	.0094	.0081	.406
.40	.0018	.0051	.141				

2,500 r. p. m.				2,600 r. p. m.			
0.15	0.0411	0.0176	0.350	0.20	0.0328	0.0164	0.400
.20	.0340	.0160	.425	.25	.0251	.0142	.442
.25	.0260	.0139	.467	.30	.0169	.0118	.430
.30	.0174	.0114	.458	.35	.0081	.0091	.312
.35	.0086	.0086	.350				

2,700 r. p. m.			
0.25	0.0239	0.0142	0.420
.30	.0162	.0121	.401
.35	.0078	.0096	.284

PROPELLER R-6 SET 6.8° AT 0.75R

1,000 r. p. m.				1,200 r. p. m.			
0.10	0.0400	0.0123	0.325	0.10	0.0400	0.0124	0.323
.15	.0352	.0121	.437	.15	.0351	.0121	.436
.20	.0304	.0118	.516	.20	.0299	.0116	.516
.25	.0250	.0111	.565	.25	.0245	.0109	.563
.30	.0188	.0099	.570	.30	.0185	.0098	.568
.35	.0125	.0085	.515	.35	.0125	.0085	.515
.40	.0053	.0069	.307	.40	.0056	.0072	.311

1,400 r. p. m.				1,600 r. p. m.			
0.10	0.0416	0.0128	0.325	0.10	0.0420	0.0130	0.324
.15	.0367	.0126	.436	.15	.0368	.0126	.437
.20	.0310	.0120	.516	.20	.0312	.0121	.516
.25	.0250	.0111	.564	.25	.0252	.0112	.564
.30	.0188	.0099	.570	.30	.0190	.0100	.570
.35	.0125	.0085	.515	.35	.0125	.0087	.504
.40	.0055	.0072	.306	.40	.0055	.0072	.305

1,800 r. p. m.				2,000 r. p. m.			
0.10	0.0432	0.0134	0.323	0.10	0.0450	0.0145	0.310
.15	.0377	.0130	.435	.15	.0392	.0137	.429
.20	.0318	.0123	.516	.20	.0329	.0128	.514
.25	.0259	.0114	.567	.25	.0264	.0118	.560
.30	.0194	.0102	.569	.30	.0197	.0106	.559
.35	.0129	.0089	.507	.35	.0123	.0090	.478
.40	.0052	.0072	.290	.40	.0042	.0072	.234

TABLE I—Continued

FINAL ADJUSTED COEFFICIENTS—Continued

PROPELLER R-6 SET 6.8° AT 0.75R—Continued

2,100 r. p. m.				2,200 r. p. m.			
$\frac{V}{nD}$	C_T	C_P	η	$\frac{V}{nD}$	C_T	C_P	η
0.10	0.0470	0.0159	0.296	0.10	0.0474	0.0168	0.282
.15	.0413	.0150	.413	.15	.0414	.0155	.401
.20	.0347	.0138	.503	.20	.0345	.0142	.486
.25	.0272	.0124	.548	.25	.0270	.0126	.536
.30	.0198	.0107	.556	.30	.0192	.0109	.529
.35	.0121	.0091	.465	.35	.0111	.0091	.427
.40	.0036	.0073	.197				
2,300 r. p. m.				2,400 r. p. m.			
0.10	0.0458	0.0179	0.256	0.10	0.0461	0.0184	0.251
.15	.0407	.0166	.368	.15	.0403	.0172	.352
.20	.0342	.0151	.453	.20	.0333	.0156	.427
.25	.0264	.0133	.496	.25	.0250	.0137	.456
.30	.0184	.0114	.484	.30	.0167	.0116	.432
.35	.0096	.0094	.357	.35	.0077	.0094	.287
2,500 r. p. m.				2,600 r. p. m.			
0.10	0.0459	0.0195	0.235	0.10	0.0437	0.0198	0.221
.15	.0396	.0179	.332	.15	.0377	.0182	.311
.20	.0320	.0161	.398	.20	.0307	.0165	.372
.25	.0238	.0142	.419	.25	.0229	.0147	.390
.30	.0152	.0122	.374	.30	.0146	.0126	.348
.35	.0063	.0100	.221	.35	.0056	.0104	.188

PROPELLER S-W-9.5 SET 6.8° AT 0.75R.

800 r. p. m.				1,000 r. p. m.			
0.05	0.0476	0.0140	0.170	0.05	0.0468	0.0140	0.167
.10	.0443	.0140	.316	.10	.0435	.0140	.310
.15	.0402	.0140	.431	.15	.0393	.0138	.427
.20	.0354	.0139	.509	.20	.0343	.0135	.508
.25	.0300	.0135	.555	.25	.0288	.0130	.554
.30	.0240	.0127	.570	.30	.0227	.0121	.563
.35	.0181	.0117	.540	.35	.0164	.0110	.521
.40	.0117	.0105	.447	.40	.0098	.0095	.412
.45	.0048	.0091	.237				
1,200 r. p. m.				1,400 r. p. m.			
0.05	0.0445	0.0132	0.169	0.05	0.0465	0.0138	0.168
.10	.0414	.0133	.310	.10	.0425	.0137	.310
.15	.0375	.0132	.426	.15	.0386	.0136	.426
.20	.0328	.0129	.507	.20	.0335	.0133	.503
.25	.0275	.0125	.551	.25	.0277	.0127	.545
.30	.0215	.0116	.555	.30	.0214	.0117	.550
.35	.0149	.0104	.501	.35	.0149	.0104	.500
.40	.0085	.0090	.379	.40	.0080	.0090	.355
1,600 r. p. m.				1,800 r. p. m.			
0.05	.0.0460	0.0139	0.165	0.05	0.0481	0.0144	.167
.10	.0427	.0138	.310	.10	.0441	.0142	.311
.15	.0386	.0136	.426	.15	.0395	.0140	.423
.20	.0336	.0133	.505	.20	.0340	.0135	.504
.25	.0277	.0127	.545	.25	.0279	.0128	.545
.30	.0214	.0117	.548	.30	.0216	.0118	.549
.35	.0148	.0104	.498	.35	.0150	.0105	.500
.40	.0078	.0089	.351	.40	.0079	.0090	.351
2,000 r. p. m.				2,200 r. p. m.			
0.05	0.0516	0.0161	0.161	0.05	0.0536	0.0180	0.149
.10	.0461	.0156	.302	.10	.0485	.0175	.277
.15	.0417	.0150	.417	.15	.0426	.0168	.381
.20	.0354	.0142	.498	.20	.0360	.0158	.455
.25	.0289	.0133	.544	.25	.0292	.0146	.500
.30	.0220	.0121	.546	.30	.0216	.0131	.495
.35	.0150	.0106	.494	.35	.0138	.0115	.420
.40	.0069	.0092	.301	.40	.0048	.0096	.200
2,400 r. p. m.				2,500 r. p. m.			
0.05	0.0530	0.0206	0.129	0.05	0.0524	0.0215	0.122
.10	.0476	.0197	.242	.10	.0466	.0205	.228
.15	.0413	.0186	.333	.15	.0400	.0193	.310
.20	.0345	.0173	.399	.20	.0338	.0184	.367
.25	.0270	.0157	.430	.25	.0254	.0162	.392
.30	.0189	.0140	.405	.30	.0175	.0144	.364
.35	.0102	.0121	.295	.35	.0089	.0127	.246
.40	.0009	.0101	.036				

TABLE I—Continued

FINAL ADJUSTED COEFFICIENTS—Continued

PROPELLER S-W-9.5 SET 6.8° AT 0.75R—Continued

2,600 r. p. m.							
$\frac{V}{nD}$	C_T	C_P	η	$\frac{V}{nD}$	C_T	C_P	η
0.05	0.0525	0.0227	0.116				
.10	.0426	.0216	.216				
.15	.0401	.0205	.294				
.20	.0329	.0189	.348				
.25	.0252	.0170	.371				
.30	.0170	.0152	.336				
.35	.0082	.0132	.217				

PROPELLER S-N-9.5 SET 6.8° AT 0.75R.

800 r. p. m.				1,000 r. p. m.			
0.05	0.0398	0.0120	0.166	0.05	0.0392	0.0110	0.178
.10	.0371	.0118	.314	.10	.0366	.0111	.330
.15	.0337	.0115	.440	.15	.0326	.0110	.444
.20	.0295	.0111	.532	.20	.0282	.0108	.522
.25	.0247	.0106	.582	.25	.0236	.0104	.569
.30	.0191	.0098	.583	.30	.0185	.0097	.573
.35	.0131	.0088	.520	.35	.0126	.0087	.509
.40	.0068	.0076	.358	.40	.0065	.0074	.352
1,200 r. p. m.				1,400 r. p. m.			
0.05	0.0398	0.0114	0.175	0.05	0.0425	0.0121	0.176
.10	.0367	.0115	.320	.10	.0388	.0120	.323
.15	.0335	.0113	.445	.15	.0347	.0117	.445
.20	.0288	.0110	.524	.20	.0295	.0113	.523
.25	.0240	.0105	.571	.25	.0244	.0107	.570
.30	.0187	.0098	.572	.30	.0187	.0098	.573
.35	.0126	.0087	.506	.35	.0123	.0085	.508
.40	.0065	.0074	.349	.40	.0060	.0070	.341
1,600 r. p. m.				1,800 r. p. m.			
0.05	0.0443	0.0126	0.176	0.05	0.0451	0.0134	0.168
.10	.0404	.0125	.323	.10	.0416	.0130	.320
.15	.0358	.0121	.444	.15	.0366	.0126	.435
.20	.0306	.0117	.524	.20	.0310	.0119	.520
.25	.0250	.0110	.569	.25	.0251	.0110	.570
.30	.0191	.0100	.573	.30	.0191	.0100	.573
.35	.0128	.0088	.510	.35	.0128	.0088	.509
.40	.0062	.0072	.345	.40	.0062	.0072	.345
2,000 r. p. m.				2,200 r. p. m.			
0.05	0.0464	0.0150	0.155	0.05	0.0477	0.0166	0.144
.10	.0425	.0145	.293	.10	.0435	.0160	.272
.15	.0378	.0138	.412	.15	.0382	.0151	.380
.20	.0323	.0128	.505	.20	.0321	.0139	.461
.25	.0263	.0118	.568	.25	.0255	.0126	.505
.30	.0196	.0105	.560	.30	.0183	.0111	.495
.35	.0127	.0091	.488	.35	.0107	.0095	.395
.40	.0056	.0075	.300	.40	.0026	.0078	.134
2,400 r. p. m.				2,500 r. p. m.			
0.05	0.0460	0.0178	0.129	0.05	0.0464	0.0190	0.122
.10	.0418	.0172	.243	.10	.0418	.0180	.232
.15	.0366	.0161	.342	.15	.0361	.0167	.324
.20	.0304	.0149	.408	.20	.0298	.0154	.387
.25	.0235	.0135	.435	.25	.0230	.0140	.410
.30	.0161	.0118	.410	.30	.0155	.0122	.380
.35	.0084	.0101	.291	.35	.0076	.0104	.255
2,600 r. p. m.							
0.05	0.0470	0.0200	0.117				
.10	.0420	.0189	.222				
.15	.0360	.0175	.308				
.20	.0295	.0160	.368				
.25	.0225	.0144	.390				
.30	.0151	.0126	.360				
.35	.0073	.0109	.235				

TABLE I—Continued

FINAL ADJUSTED COEFFICIENTS—Continued

PROPELLER S-W-9 SET 10° AT 0.75*R*.

1,200 r. p. m.				1,400 r. p. m.			
$\frac{V}{nD}$	C_T	C_P	η	$\frac{V}{nD}$	C_T	C_P	η
0.10	0.0584	0.0200	0.292	0.10	0.0576	0.0200	0.288
.15	.0535	.0198	.405	.15	.0537	.0200	.402
.20	.0483	.0196	.493	.20	.0491	.0199	.493
.25	.0431	.0191	.564	.25	.0440	.0196	.562
.30	.0379	.0184	.619	.30	.0387	.0188	.617
.35	.0324	.0175	.648	.35	.0327	.0177	.646
.40	.0266	.0162	.656	.40	.0263	.0161	.652
.45	.0208	.0147	.637	.45	.0198	.0143	.622
.50	.0146	.0129	.566	.50	.0130	.0122	.533
.55	.0077	.0104	.407	.55	.0062	.0100	.341
1,600 r. p. m.				1,800 r. p. m.			
0.10	0.0580	0.0202	0.287	0.10	0.0598	0.0209	0.286
.15	.0536	.0201	.400	.15	.0552	.0207	.400
.20	.0487	.0199	.489	.20	.0499	.0203	.491
.25	.0435	.0194	.560	.25	.0445	.0198	.561
.30	.0380	.0186	.612	.30	.0388	.0190	.612
.35	.0322	.0176	.640	.35	.0326	.0177	.645
.40	.0260	.0161	.656	.40	.0261	.0160	.651
.45	.0195	.0142	.618	.45	.0194	.0141	.620
.50	.0128	.0120	.532	.50	.0125	.0118	.530
.55	.0060	.0097	.340	.55	.0052	.0092	.311
2,000 r. p. m.				2,100 r. p. m.			
0.10	0.0638	0.0234	0.272	0.10	0.0654	0.0252	0.259
.15	.0587	.0229	.385	.15	.0603	.0245	.369
.20	.0530	.0221	.480	.20	.0546	.0235	.465
.25	.0470	.0210	.559	.25	.0485	.0221	.549
.30	.0405	.0198	.613	.30	.0418	.0204	.615
.35	.0340	.0183	.650	.35	.0348	.0185	.655
.40	.0270	.0165	.655	.40	.0270	.0165	.654
.45	.0198	.0144	.618	.45	.0198	.0143	.623
.50	.0122	.0118	.517	.50	.0120	.0120	.500
.55	.0048	.0094	.281				
2,200 r. p. m.				2,300 r. p. m.			
0.10	0.0640	0.0258	0.248	0.10	0.0633	0.0275	0.230
.15	.0599	.0253	.355	.15	.0595	.0268	.333
.20	.0550	.0244	.450	.20	.0550	.0258	.426
.25	.0495	.0233	.531	.25	.0495	.0243	.508
.30	.0430	.0217	.595	.30	.0430	.0227	.567
.35	.0358	.0196	.640	.35	.0360	.0205	.614
.40	.0280	.0172	.651	.40	.0286	.0180	.635
.45	.0196	.0144	.613	.45	.0205	.0152	.606
.50	.0106	.0113	.469				
2,400 r. p. m.				2,500 r. p. m.			
0.15	0.0610	0.0276	0.331	0.25	0.0452	0.0243	0.465
.20	.0552	.0267	.413	.30	.0401	.0234	.514
.25	.0486	.0252	.482	.35	.0340	.0216	.550
.30	.0418	.0232	.540	.40	.0263	.0190	.554
.35	.0345	.0209	.578				
.40	.0269	.0182	.590				
.45	.0187	.0154	.546				

PROPELLER S-N-9 SET 10° AT 0.75*R*

800 r. p. m.				1,000 r. p. m.			
$\frac{V}{nD}$	C_T	C_P	η	$\frac{V}{nD}$	C_T	C_P	η
0.10	0.0513	0.0183	0.280	0.10	0.0520	0.0180	0.289
.15	.0484	.0181	.401	.15	.0485	.0181	.402
.20	.0450	.0180	.500	.20	.0445	.0180	.495
.25	.0406	.0177	.574	.25	.0403	.0177	.569
.30	.0358	.0173	.621	.30	.0354	.0170	.624
.35	.0304	.0166	.640	.35	.0299	.0158	.663
.40	.0244	.0155	.630	.40	.0240	.0143	.672
.45	.0181	.0140	.581	.45	.0179	.0126	.641
.50	.0118	.0120	.492	.50	.0115	.0105	.549
.55	.0045	.0093	.266	.55	.0043	.0080	.296

TABLE I—Continued

FINAL ADJUSTED COEFFICIENTS—Continued

PROPELLER S-N-9 SET 10° AT 0.75*R*—Continued

1,200 r. p. m.				1,400 r. p. m.			
$\frac{V}{nD}$	C_T	C_P	η	$\frac{V}{nD}$	C_T	C_P	η
0.10	0.0520	0.0179	0.290	0.10	0.0539	0.0183	0.294
.15	.0483	.0181	.400	.15	.0498	.0182	.410
.20	.0443	.0180	.493	.20	.0450	.0180	.500
.25	.0397	.0175	.566	.25	.0400	.0173	.578
.30	.0347	.0166	.626	.30	.0347	.0163	.637
.35	.0292	.0153	.667	.35	.0289	.0150	.674
.40	.0237	.0140	.677	.40	.0230	.0136	.676
.45	.0172	.0121	.640	.45	.0167	.0117	.641
.50	.0110	.0100	.550	.50	.0101	.0094	.537
.55	.0042	.0077	.300	.55	.0038	.0070	.299
1,600 r. p. m.				1,800 r. p. m.			
0.10	0.0550	0.0185	0.297	0.10	0.0568	0.0195	0.291
.15	.0503	.0185	.407	.15	.0521	.0195	.401
.20	.0455	.0184	.495	.20	.0471	.0192	.491
.25	.0402	.0177	.568	.25	.0418	.0184	.568
.30	.0347	.0168	.620	.30	.0360	.0173	.624
.35	.0288	.0153	.658	.35	.0298	.0158	.660
.40	.0228	.0137	.665	.40	.0235	.0141	.666
.45	.0166	.0117	.638	.45	.0168	.0120	.630
.50	.0100	.0091	.550	.50	.0100	.0095	.526
.55	.0036	.0067	.296	.55	.0031	.0067	.254
2,000 r. p. m.				2,100 r. p. m.			
0.10	0.0568	0.0211	0.269	0.10	0.0563	0.0216	0.260
.15	.0529	.0210	.377	.15	.0527	.0215	.368
.20	.0482	.0203	.474	.20	.0483	.0210	.460
.25	.0430	.0194	.554	.25	.0435	.0199	.546
.30	.0374	.0182	.616	.30	.0379	.0186	.611
.35	.0311	.0165	.659	.35	.0320	.0170	.359
.40	.0245	.0146	.671	.40	.0252	.0151	.668
.45	.0175	.0124	.635	.45	.0183	.0129	.638
.50	.0105	.0102	.514	.50	.0106	.0104	.510
2,200 r. p. m.				2,300 r. p. m.			
0.10	0.0577	0.0239	0.241	0.10	0.0588	0.0253	0.232
.15	.0540	.0232	.348	.15	.0551	.0248	.334
.20	.0493	.0222	.444	.20	.0504	.0239	.422
.25	.0437	.0209	.522	.25	.0449	.0225	.498
.30	.0376	.0193	.585	.30	.0384	.0206	.559
.35	.0310	.0172	.630	.35	.0315	.0184	.598
.40	.0241	.0151	.640	.40	.0237	.0156	.608
.45	.0162	.0128	.570	.45	.0151	.0123	.553
2,400 r. p. m.				2,500 r. p. m.			
0.15	0.0550	0.0260	0.317	0.25	0.0442	0.0240	0.460
.20	.0505	.0250	.404	.30	.0379	.0222	.512
.25	.0450	.0234	.480	.35	.0302	.0195	.542
.30	.0384	.0214	.538	.40	.0217	.0163	.532
.35	.0310	.0188	.576				
.40	.0232	.0160	.580				
2,600 r. p. m.							
0.30	0.0358	0.0221	0.486				
.35	.0292	.0196	.521				
.40	.0217	.0170	.511				

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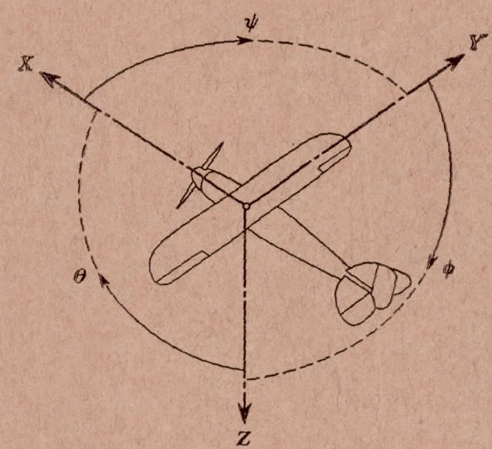

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	ϕ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	ψ	w	r

Absolute coefficients of moment

$$C_l = \frac{L}{qbS} \qquad C_m = \frac{M}{qcS} \qquad C_n = \frac{N}{qbS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p, Geometric pitch.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slipstream velocity.
T, Thrust, absolute coefficient $C_T = \frac{T}{\rho n^2 D^4}$
Q, Torque, absolute coefficient $C_Q = \frac{Q}{\rho n^2 D^5}$
P, Power, absolute coefficient $C_P = \frac{P}{\rho n^3 D^5}$.
C_s, Speed power coefficient $= \sqrt[5]{\frac{\rho V^5}{P n^2}}$.
η, Efficiency.
n, Revolutions per second, r. p. s.
Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS

1 hp = 76.04 kg/m/s = 550 lb./ft./sec.
1 kg/m/s = 0.01315 hp
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.
1 lb. = 0.4535924277 kg
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.